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The basic purpose of this project was to develop a conceptual framework for estimating the social welfare gains or benefits of reducing current noise levels in urban environments. The project has concentrated on developing economic welfare theory and empirical techniques to assess willingness-to-pay by individuals for noise avoidance. Particular attention was paid to noise produced by motor vehicles and noise produced by operations at construction sites.

The theoretical effect of the localized nature of noise on people's willingness-to-pay to control noise was investigated and found to be important. An efficient pricing scheme for aggregate noise disturbance was devised, based on people's willingness-to-pay for noise reduction. A systematic analysis of the case of many suppliers of the public good of noise reduction was carried out.

A questionnaire was developed to elicit responses on the physical and psychic costs of noise in urban areas. This questionnaire will attempt to assign dollar values to the costs of noise pollution by determining people's willingness-to-pay to control or reduce noise.

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ECONOMIC WELFARE IMPACTS OF URBAN NOISE

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Contract No. 68-01-2634

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ABSTRACT

The basic purpose of this project was to develop a conceptual framework for estimating the social welfare gains or benefits of reducing current noise levels in urban environments. The project has concentrated on developing economic welfare theory and empirical techniques to assess willingness-to-pay by individuals for noise avoidance. Particular attention was paid to noise produced by motor vehicles and noise produced by operations at construction sites. Noise pollution produced at airports and by aircraft was purposely de-emphasized in this study.

The theoretical effect of the localized nature of noise on people's willingness-to-pay to control noise was investigated and found to be important. The theoretical effect of noise averting activities on people's willingness-to-pay to control noise was also found to be significant. An efficient pricing scheme for aggregate noise disturbance was devised, based on people's willingness-to-pay for noise reduction. A systematic analysis of the case of many suppliers of the public good of noise reduction was carried out.

A questionnaire was developed to elicit responses on the physical and psychic costs of noise in urban areas. This questionnaire will attempt to assign dollar values to the costs of noise pollution by determining people's willingness-to-pay to control or reduce noise.

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SUMMARY

Willingness-to-pay for the regulation of noise disturbance was investigated and found to be a valid and determinable indicator of people's annoyance with noise. The economic effects of the fact that noise is a very localized phenomenon were also investigated and found to be very important. A pricing scheme for aggregate noise disturbance was devised, based on people's willingness-to-pay for noise reduction. This derivation indicates that with respect to Pareto efficiency it makes no difference whether the public is compensated for damage due to noise or the producers of the noise are taxed. An attitudinal survey was developed to determine people's willingness-to-pay for specific reductions in overall noise level. This questionnaire was pretested and found to be a valid instrument for determining people's willingness-to-pay for noise reduction. The results of the pretest were also used to determine the size of the sample for the actual test, the seasonal period of sampling, and the distributional characteristics of the population to be sampled.

RECOMMENDATIONS AND CONCLUSIONS

Our principal recommendation is that the questionnaire on noise, that we devised and pretested, be administered to a sample chosen according to the rules we developed. We believe that certain modifications should be made in certain of the questions in the survey, but that these modifications are basically rather minor. Following the administration of the questionnaire to the sample chosen, we recommend that the results of the survey be analyzed extensively by several different techniques, including regression analysis and possibly principal components analysis or discriminant analysis.

Our principal conclusions are the following:

1. Willingness-to-pay for the regulation of noise disturbance is a valid and determinable indicator of people's degree of annoyance with noise;
2. A questionnaire is a valid instrument for determining people's willingness-to-pay for specific reductions in overall noise level; and
3. The determination of willingness-to-pay for noise reduction by the public is essential for setting efficient and effective standards for noise control.

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All errors of fact and faults of judgment and omission are the authors' responsiblity.

CHAPTER I

INTRODUCTION

This report represents QEI's Final Report to the Environmental Protection Agency on Contract No. 68-01-2634 entitled "Economic Welfare Impacts of Urban Noise." The purpose of this contract is to develop a conceptual framework for estimating all social welfare gains or willingness-to-pay indicators for reducing current levels of noise in urban areas. In order to perform this study two main areas were investigated. First, an economic welfare theory and empirical techniques to assess individual willingness-to-pay for noise avoidance or reduction were developed. Second, a questionnaire was designed to elicit responses from individuals on the psychic costs of noise in urban environments. This questionnaire was then pretested on a sample of people drawn from the Boston metropolitan area.

Noise is defined to be unwanted sound. Noise is, in large part, a subjective phenomenon relating to the reactions of people to certain types of physical sound. Noise may well have adverse effects on the physical, mental, and emotional health of some members of the public, but the form of the relationship between noise and health is unknown. However, noise certainly is the cause of much irritation and annoyance to a large part of the public. The degree of annoyance caused members of the public is, of course, subjective and varies from person to person.

In economic terms, noise is considered to be an externality, produced as an unintentional, but usually unavoidable, by-product during the production of some other good or service, such as the provision of transportation services. The production of noise as an externality is usually unintentional and not particulary desired by the producers. The benefit of noise to the producers is usually zero, but the cost of noise to the public is larger than zero. However, it would certainly cost many of the producers of noise large sums of money to reduce the noise produced by them as a by-product. The question arises as to who should bear this additional production cost for reducing the noise produced. Either the producers or consumers must bear this cost, and it seems clear that ultimately the consumers will bear virtually the entire cost of noise reduction through higher prices on consumer products. Thus, it seems essential to determine how much the public is willing to pay for noise reduction.

It should be noted that the free competitive market can not handle the situation that arises due to the effects of noise or any other externality. This is because noise is, in part at least, a so-called public good. For a moderate expenditure, few can totally isolate themselves from the effects of noise. Also, what one person does to protect himself from the effects of noise in no way protects anyone else from its effects. Thus, it seems clear that the government must intervene to protect most of the members of the public from the effects of noise. But, in situations such as this, the government must be seen as acting fairly and equitably toward all concerned.

Noise is, of course, similar in many of its effects to other externalities such as water or air pollution. However, in certain important respects noise differs markedly in its effects from water or air pollution. These differences necessitate a somewhat different analysis and treatment of noise pollution from that of air or water pollution. The following paragraphs present a discussion of some of the most important differences between noise pollution and air or water pollution.

First, noise is a very localized phenomenon affecting individuals almost solely. Noise produced at a certain location can only be heard by, and will only have an effect on people within a certain distance of the location of the noise source, since the intensity of noise diminishes rapidly with the distance from its source of production. This suggests that the regulation and control of noise pollution should be on a local basis or should proceed on an area-by-area basis. Since all the noise that affects a certain area is produced in or near that area, regulation and reduction of noise could certainly be accomplished on an area-by-area basis (unlike air pollution which can be transported substantial distances from its source of production). The fact that noise is a local phenomenon also implies that people have additional options in avoiding noise around their residences say, i.e., they can change their place of residence to some quieter location or they can plan to be absent from their residences during the noisiest times of the day.

Second, noise ceases to exist almost as soon as it has been produced, unlike air pollution. This implies that for a noise to exist continuously over a period of time it must be continuously produced by the source. Thus, two very different types of noise are possible, noises that last a very short time, like the sound of a pistol shot, and noises that remain at approximately the same intensity for a period of time, such as that produced by a truck traveling at constant speed. Thus, there is a tremendous variation in the noise intensity level over time, implying that standards or regulations for noise control must consider both the average intensity level of noise (during a typical day) and the maximum noise intensity level attained. Both the intensity peaks of noise and the average levels must be considered in any policy of control. This variation in noise level during any period of a day or more also raises the possibility of imposing different standards for different parts of the day, say requiring substantially lower maximum noise levels at night when people are more liable to be disturbed.

Third, the degree or extent of the effects of noise on people's physical, mental or emotional health have not been definitiely determined except in a few extreme cases. Thus, using the effects of noise on health as a means for setting noise regulations seems to be precluded. The principal effects of noise on people appear to be through the annoyance or irritation caused them. However, degree of annoyance or irritation is very difficult to assess precisely, implying that setting of noise regulations or standards on the basis of degree of public annoyance will also be rather difficult. Also, noise appears to affect different people differently; some persons seem to be far more sensitive to noise of a certain level than are others. This wide variation in individual sensitivity to noise makes an assessment of the annoyance or damage caused by a certain level of noise even more difficult.

Fourth, it is fairly easy for many people to do much to shield themselves from the adverse effects of noise pollution, unlike air pollution, from which it is hard to protect oneself. People can purchase air conditioners or double-pane glass for their windows, and thus protect themselves from a fairly high degree of noise. People can also avoid noise by staying away from their homes during particularly noisy periods. But such purchases or actions will only reduce the effect of noise pollution on the purchaser; usually no one else will obtain any benefits from such a purchase. However, probably the government should set noise regulations which will benefit everyone. But, those who have already purchased such noise-reducing devices or those who have taken steps to avoid noise will certainly receive less benefit from such regulations and will therefore be less willing to pay part of the costs for establishing such regulations.

To perform this study we were required to accomplish the five tasks listed in the Statement of Work for this contract. Task A - a literature review on the economic welfare impacts of noise pollution - resulted in the annotated bibliography which comprises the Reference Section of this report. Task B - development of an economic welfare theory and empirical techniques to assess willingness-to-pay by individuals for noise avoidance or reduction - resulted in Chapter II of this report, written by Dr. Richard Zeckhauser consulting for QEI and in Chapter III. Task C - designing a questionnaire to elicit responses on the psychic costs of noise in urban areas - resulted in the questionnaire presented in Figure 4.1 and the discussion given in Chapter IV. Task D - pretesting the questionnaire on a sample of people drawn from the Boston metropolitan area - and Task E - using the results of this pretest to derive a procedure for selecting the sample of persons to be tested with the final version of the questionnaire, such procedure to include the size of the sample, the seasonal period or duration of sampling, and the distributional characteristics of the population - resulted in the discussion presented in Chapter V.

CHAPTER II

WILLINGNESS-TO-PAY AS AN EFFICIENCY GUIDE FOR THE REGULATION OF NOISE DISTURBANCE

by Richard Zeckhauser

Introduction

Noise is an economic commodity. Its presence as a disturbing factor affects the welfare of individuals. In this regard it is no different than food, health, or television sets. The physical properties of noise are such that no market can exist so that the disturbance it produces can be bought and sold in the manner of apples and pears. One consequence of this inability to conduct market transactions is that the government may wish to play a regulatory role in determining what sorts of noise disturbances are generated in which locations.

If the government is to intervene in this manner, it will have to have information on what noise disturbance or its absence is worth to individuals. The purpose of this essay is to provide a framework suggesting what information is appropriate to gather for this purpose, and to detail the manner in which it could be profitably employed.

The Characteristics of Noise and Government Regulation section describes the market failures associated with noise, details some key characteristics of noise as a commodity, and then describes some special characteristics relating total noise disturbance to the noise outputs of different producers.

The section entitled Consumer Valuation discusses difficulties in determining consumers' valuations of noise disturbances. It lays out the methodology supporting the willingness-to-pay approach, and presents as well some of the principal arguments for alternative frameworks.

The third section of the essay describes the way consumer valuations should be employed when Defining the Efficient Outcome. Three major methodological considerations are set forth which must be explicitly considered when defining efficient levels for noise disturbance.

1. Possibilities for noise averting activities must be explicitly recognized when making willingness-to-pay determinations.
2. Since noise disturbance is a local phenomena, and since individuals can shift locations in response to changes in noise levels, a general equilibrium model should be employed to determine the value of noise reductions in particular locations.
3. The determination of efficient noise levels should recognize the costs of changing present patterns of noise levels and averting behaviors.

The concluding section of this essay traces the implications of the analysis for different noise valuation procedures, and then provides a more summary conclusion.

A. THE CHARACTERISTICS OF NOISE AND GOVERNMENT REGULATION

1. A Catalogue of Market Failures Associated with Noise

The first question to be considered when evaluating the possibility of government intervention to regulate the generation of noise is: Why will not the private market handle the problem? No one suggests after all that the government should regulate the production of carrots or paper clips. What are the special characteristics of noise that could lead to some collective policy concern?

Externalities

The most obvious problem is the simple one of externalities. When Smith's truck rumbles down Jones' street it disturbs Jones, but Jones takes no part in the decision as to whether or where the truck should be driven. An externality is simply a situation where there are individuals whose welfare is affected by an activity but have not voluntarily complied to take part in that activity. The primary principle supporting the efficiency of the outcome produced by voluntary trading among unhindered individuals is violated. Individuals affected by some activity can not escape participation, despite the possible detriment to their own welfare.

That noise does indeed convey externalities is made evident by the frequently employed term noise pollution. The understanding conveyed by the term pollution in general is that there is some commonly owned property resource that is being exploited for individual gain. In the more familiar case of water or air, it is that medium. When sludge is dumped in the river it becomes less attractive for swimming. When particulate is released to the air, quality of breathing diminishes. When noise is generated it is frequently said that it pollutes the airways, in the sense that other activities (including silence) for using the airways are prescribed. A may wish to carry on a conversation but find it impossible because the honking of B's horn renders ordinary conversation tones inaudible. In this essay, we shall employ the term noise disturbance where others might have referred to noise pollution.

Externalities and Privately-Received Noise

Only a portion of the problems of noise possess the characteristics just outlined to be associated with externalities. For example, it is frequently stated that the government should have a role regulating the noise level in factories. The argument against such participation can be made as follows: For the most part individuals can freely choose whether or not to work in a particular factory. If a noise situation is truly unpleasant or detrimental to their welfare, they need not work unless an appropriate wage differential is offered.

If all markets were functioning perfectly this argument against governmental participation in the market for privately received noise would be telling. There must be some things special about noise, no doubt characteristics that it shares with other environmental elements, that at least suggest the government might play a role. Two issues seem of particular interest. First, individuals may be relatively ill equipped to assess the consequences of noise. They may understand, indeed have strong feelings about, the level of noise disturbance. But they may not know whether or how it will impair their hearing, mental health, or any of a variety of other factors.

Second, the government may have a parochial interest in noise control to the extent that it might make transfer payments or pay for services for those who suffer from noise. If loss of hearing raises the probability of unemployment or a dependent welfare status, then the government may have a strong incentive from a pure efficiency standpoint to discourage activities that might encourage hearing loss. The same principle would apply to other adverse consequences of noise disturbance.

This suggests that even where individuals voluntarily accept some level of noise disturbance (what might be called contractual noise), in which case it can be assumed that they are demanding some compensation, the government may still have an interest in the regulation of the level of noise disturbance.

2. Noise Disturbance - Special Characteristics

In what ways might the economic qualities of noise disturbance differentiate it from other types of externalities, which would lead either to different modes for assessing willingness-to-pay, or would possibly suggest alternative procedures for improving the situation? A great number of factors can be identified:

1) Those who suffer from noise disturbance may have considerable latitude in reducing its effects upon them.

2) Though any particular source may affect the welfares of a large number of individuals, unlike air pollution for example, it can frequently be locally controlled.

3) Once again unlike air pollution or potential radiation pollution, its dispersion and incidence can be fairly accurately predicted, for a given location.

4) Unlike many classic examples of externalities, the effects of the externality fall almost exclusively on individuals. The effects on firms come only indirectly via its impact on individuals. (This situation might be contrasted with that say of water pollution. Dirty water may make it substantially more expensive for a variety of industrial processes that require water to operate.)

5) The producers of the externality, and this is particularly the case with traffic noise, are numerous, and perhaps more important, their identities change rapidly from day to day.

6) Noise disturbance is most profitably assessed on a location specific basis. Within a relatively small geographic area, say a few square blocks,

the noise level may be exceedingly variable. Moreover, the valuation of the noise disturbance may also shift rapidly from location to location.

7) In many situations, the noise disturbance shifts rapidly over the course of the day, indeed within any hour. Individuals are likely to be sensitive to variations in noise level, which suggests that measures that rely solely on averages will be inappropriate for individuals' valuations. Procedures for assessing noise disturbance should recognize stochastic variation.

Individual Latitutde in Reducing Effects

The understanding that individuals can affect the impact of noise externalities, suggests some directions for willingness-to-pay calculations. First, if any changes are to be made in levels of noise, a general equilibrium framework should be employed to assess its consequences. The purpose of such a framework would be to enable the analyst or policymaker to determine more exactly what the change in the level of noise disturbance would be worth to society, as indicated perhaps by willingness-to-pay. If it is mistakenly assumed that present levels of averting activity will remain unchanged, and if it is also incorrectly supposed that individuals will not be changing their locations, the policymaker's determinations will be in error. Moreover, as we shall show later in our discussion of the General Equilibrium Model, there will be a bias toward undercrediting the gains from reductions in noise disturbance and overestimating the costs of an increase in noise disturbance. (From a policy standpoint, this will produce a bias toward the status quo.)

Second, as an equity argument, adjusting noise levels and/or providing compensation in response to present conditions may not restore the welfares of individuals to the levels that would be achieved had they been given initial property rights. If they have already undertaken substantial action to screen out the undesirable effects of the externality, compensation for this reduction effort should also be made.

On the other hand, if compensation is paid, or regulations imposed employing as the model for thought the fact that individuals will not be able to take defensive actions, either of two unfortunate consequences may result. They may be overcompensated, or alternatively the level of regulation may be set too strictly.

More than noise proofing a home or turning on air conditioning can be done to reduce the effects of noise. Individuals can change their purchases so that they do not encounter the noise. For contractual noise, say a dishwasher, they can merely purchase another brand. Most non-contractual noise bears a geographic dimension not under an individual's control. That is, he can not buy whether or not a particular car passes down the street. In this instance, therefore, the individual has the most significant option to change his location. But location selection is a most particular way to diminish the impact of externalities, and one that is insufficiently examined in the literature. First, unlike the purchase of other goods that maintain externalities, most individuals purchase only one location, say for their home. Moreover, no two individuals can purchase the same location. (Although an apartment house can replace a single family dwelling.) And even if we look over the course of say a week to see where an individual is spending his time in an effort to overcome single-location effects, no individual will be able to escape the constraint that in effect he gets one week's worth of locations. There can be no equivalent to increases or reductions in purchases. The strong ties of noise externalities to locations suggest that some form of geographic model should be employed to assess willingness-to-pay. Such a model is developed below under the heading Noise and Location in a General Equilibrium Model.

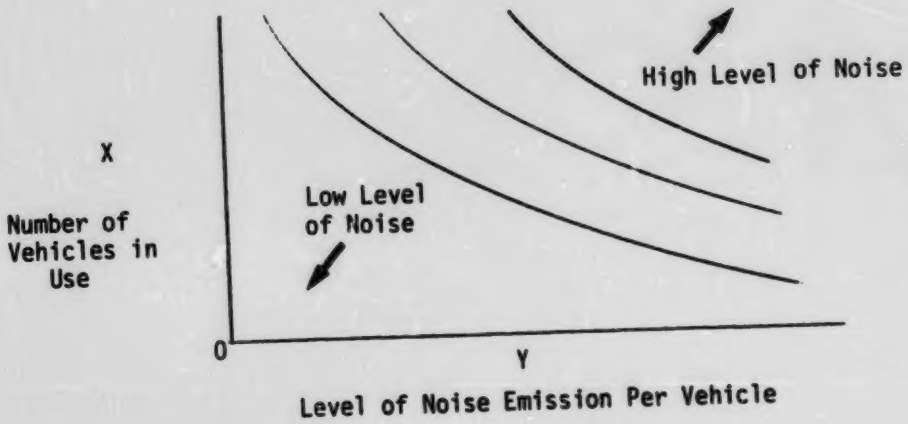
Sources Subject to Local Control

The strong example in this instance is traffic noise. Whatever the level of noise emanating from trucks, buses and automobiles, the direction of traffic makes it possible to make one street or neighborhood noisy and another quiet. An ideal strategy for looking at the control of the noise externality would examine tradeoffs between controlling the level of noise emanating from the traffic itself, reducing the amount of noise from any particular vehicle passing any particular point, and directing the flow of traffic, say from street A to street B. Represent these possible strategies as X representing control of the number of vehicles in use, Y indicating control of the level of noise emission per vehicle, and Z as representing a strategy for influencing the location of the traffic. Any or all of these control measures may be represented by a vector. Thus, a vector for X might have as its elements the numbers of vehicles of different classifications identified according to the noise disturbances they produce.

Assume for present discussion that the population to be affected by noise disturbance was either in place (so the effects of the traffic noise upon it could be computed directly), or that the effects of any particular pattern of noise emanation could be accurately predicted. A noise control strategy would then consist of dealing with each one of these factors. What should be done with X will depend on potentialities for Y and Z and vice versa. In general, it might be expected that if Y were readily manipulable, then we might wish to undertake less severe efforts for dealing with X and Z. The conceptual model implicit in such an argument has something to do with a notion of total disturbance of the noise, which might be represented as D = f(X,Y,Z). A priori arguments are not sufficient to make an unambiguous determination of the structure of the f function. But intuition would suggest that more likely than not, cross partial derivatives will be negative. This would imply, for example, that the returns to a rigid policy of traffic control would be greatest when the vehicles themselves were creating more rather than less noise disturbance.

If this property does hold, then different noise-disturbance control strategies will compete with each other. We may wish to have more control at the vehicle level, but less rigid direction of traffic patterns. A two-dimensional cross section of the production function for noise disturbance would have the following form.

Fig. 2.1 Levels of Noise Disturbance with Z Fixed



Effective government policy for noise control will recognize the tradeoffs between different regulatory approaches. The mix of possibilities may be a rich one. Policy for the control of noise disturbance is confronted with an additional set of complications because noise is not an additive commodity in the sense that total noise disturbance equals the sum of separately calculable disturbances coming from a variety of producers. This implies that regulatory policy for noise will have to pay particular attention to the structure of the production function for noise disturbance. It is to that subject that we now turn.

3. The Production Process for Noise Disturbance

Traditional discussions treat external diseconomies as if they were a homogeneous commodity. The total amount of the externality produced is the sum of the amounts produced by all individuals and firms together. Let x_i identify the output of source i. Then the total amount of disturbance can be indicated $N = \sum_i x_i$.

There are two reasons why the undesirable effects of noise should not be thought to possess these properties. First, its incidence is a geographical phenomenon (as for that matter are many other externalities that are not always described this way). This suggests that we should not think of a single externality, say noise disturbance in the community, but rather something more personalized. At the most micro level it would be noise disturbance to Jones, noise disturbance to Smith, etc. To make the analysis more adaptable to measurement and control, some larger unit of analysis is likely necessary. We might then have noise along upper Main Street, noise along the downtown sections of Elm Street, noise in the high school classrooms, etc.

Second, noise is not an additive phenomenon. This study does not suggest what is the appropriate function for aggregating noise disturbances emanating from different sources. But it does point out that the additive-form simplification, despite its merits when dealing with many other forms of externalities, is not appropriate for noise.*

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*In Part I, Chapter 2 of this report, Thomas Holmes shows that the traditional efficiency condition for externalities and public goods production holds in the case of noise, despite the fact that noise disturbance is not an additive commodity. At the efficient point, each producer of noise should be operating so that his marginal cost of noise reduction just equals summed willingness-to-pay to reduce his noise.

If there is some aggregate measure of noise that is accepted by the entire community, then as Holmes shows, the appropriate efficiency condition is that each noise producer must balance his cost of noise reduction against the product

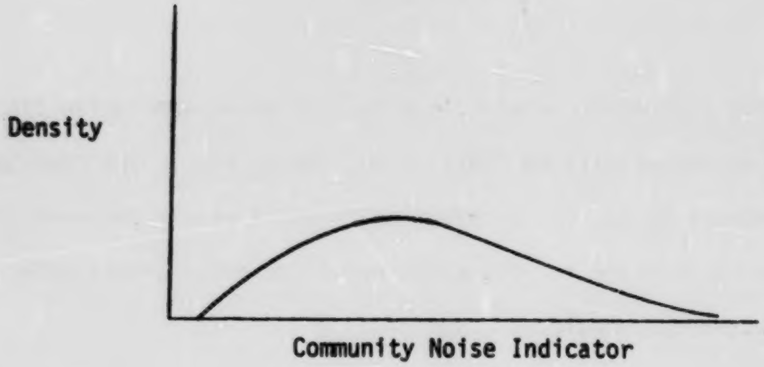
summed willingness-to-pay to reduce aggregate disturbance	×	the marginal contribution of a unit of his noise reduction to aggregate reduction of disturbance.

The problem is that the amount of disturbance, as indicated by some willingness-to-pay notion, deriving from one noise source will be substantially affected by the presence or absence of other sources. If there is a continuous traffic background noise ranging about 50 decibels, individuals talking loudly on the street are hardly likely to disturb someone trying to sleep in the roadside hospital. Requiring them to whisper would not make sense. Any measure of noise is multi-dimensional. Even if matters were additive on each one of those dimensions, and they hardly can be assumed to be such, that would not imply that the summary measures of three different noise disturbances would be additive.

The whole problem of aggregating is complicated by the stochastic nature of the noise problem. Let us assume that we accepted a single measure of noise disturbance, say decibel level. The decibel level varies continuously within the course of the day, indeed within each minute. Frequently statistical measures are proposed as a means of dealing with this variation. Take as an indicator the first or tenth percentile of noise level over the course of the day. But this is just an approximation that makes the assessment process manageable. It might be far preferable to assess the distribution of noise levels over the day and assign some valuation function. If individuals' valuation functions could be reduced to a few parameters, computing the mean and the variance of the decibel level might be appropriate.

A procedure whose widespread use and tractability means that it should at least be considered for assessing total noise disturbance would find for each level of disturbance both its likelihood of occurrence and its valuation. These would be multiplied together, then cumulated over all levels of disturbance. The analysis might be as follows:

Fig. 2.2. Density Function for Noise



Let us denote this density function as f(N). The community noise indicator is a variable that is expected to correlate well with the degree of noise disturbance. Other measures might be employed. If individuals were quite dissimilar in the qualitative aspects of noise that disturbed them, then multiple indicators might be necessary.

This little illustration does not distinguish between noise during the day and noise at night. If, as would seem likely, individuals feel quite differently about noise during these periods, then it might be worthwhile to deal with distinct distributions for the two time periods. Similarly, it might be worthwhile to factor the noise disturbance along other dimensions. (Other portions of this analysis discuss the importance of identifying noise on a location-by-location basis. Indicators that take say a community-wide view are likely to be much too aggregative.)

This analysis deals with a single indicator. It is assumed that an individual values total noise disturbance by summing his minute-by-minute valuations. Indicate the per minute valuation as V(N); his total valuation of a particular distribution of noise would be:

$$\int_0^\infty f(N)V(N)dN \quad .$$

(For many noise indicators values close to 0 or above some quite finite values would be exceedingly unlikely if not impossible.) The computation of his willingness-to-pay for a reduction in noise merely compares this integral with another one for the after-reduction noise distribution $f^*(N)$. The willingness-to-pay would be

$$\int_0^\infty f(N)V(N)dN - \int_0^\infty f^*(N)V(N)dN \ ,$$

which can be written

$$\int_0^\infty (f(N) - f^*(N))V(N)dN \ .$$

This type of valuation procedure is straightforward and manageable. Matters could become quite complex, however, if the valuation could not be determined by summing in this separable form. For certain individuals it is sometimes alleged substantial changes in noise level are what is disturbing, not an average level. If this were true, we might discover that individuals would prefer to be subjected to noise distribution A or noise distribution B rather than an alternation or mixture of the two.

What does this all suggest about the way willingness-to-pay calculations should be assessed and employed? Quite simply, unless valuations are continuously responsive to small changes in the distribution of noise, willingness-to-pay responses may be volatile. This would imply first that extrapolations between different points of assessment should be undertaken with caution. Second, corner solutions should be examined, for they may turn out to be optimal.

In the next sections we examine in detail the motivation for the willingness-to-pay approach and some difficulties associated with employing it.

B. CONSUMER VALUATION

1. Noise as a Commodity - Difficulties in Valuation

Individuals may well have significant difficulty valuing noise as a commodity. It is not a tangible good such as apples and pears. We rarely purchase it even implicitly on some open market. Our reactions to noise frequently change with exposure over time. Consumers hardly have information with which they can sensibly determine what the long-term effects of noise on them may be.

What should be made of this ignorance? That consumers are not informed about the effects of noise is not sufficient grounds to argue they will undervalue its consequences. They may exaggerate on the other side. (The evidence suggests, for example, that individuals overvalue what physicians can do by way of improving their health.) But it does suggest that individuals' uneducated estimates of the value of noise reduction may show substantial variance about the amounts they would eventually come to if they could be fully informed. An early issue which any policy intervention designed to gauge consumer preferences in order to determine where regulatory policies should be attempting to ameliorate noise levels is the issue of consumer ignorance.

If scientific determination of the consequences of noise suggest that individuals' assessments are systematically biased one way or the other, the possibility is raised of a paternalistic intervention. Issues surrounding the paternalism question are explored below.

Quite beyond consumer ignorance, the scientific establishment itself is not fully informed on the long-run consequences of exposure to different types of noise. How should government policy deal with uncertainties surrounding the consequences of a particular form of environmental damage? This is a question that has been faced in other areas of environmental regulation, though not always directly. It must be faced here.

Scientific or Governmental Uncertainty About Damage From Noise

Consider a situation where the government has determined the amounts individuals would be willing to pay to be protected against certain levels or types of noise. The queries have originally been raised where individuals are not informed about the best scientific estimates of the consequences, but must draw their own inferences. Is information of this degree of reliability sufficient for the government to make a determination of where noise levels should be established?

The answer, of course, is what other information might be made available. Acton in a pioneering work on determining individuals' willingness-to-pay for health protection conducted a survey inquiring on the value of individuals in having mobile cardiac units available. The work provides a useful parallel. Acton surveyed a number of individuals on this subject and recognized that they could not intelligently assess their potential gains should these units be made available.* Therefore, he provided individuals with some most helpful information. Thus, to a forty-year old male, he suggested: Your probability of being alive because a mobile cardiac unit is available is .45%. How much would you pay to have the unit? Clearly the answer to this question should make more sense in guiding any policy decision on the units than the answer to the uninformed question how much would you pay for the unit.

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*See Jan Acton, "Evaluating Public Programs to Save Lives: The Case of Heart Attacks," RAND Corporation, R-950-RC, January 1973.

Unfortunately, Acton also discovered that individuals had difficulty interpreting the information he provided them. Thus, for example, individuals in a higher risk pool offered much less than proportionately more for this form of protection. This was despite the fact that the dollar amounts involved were insufficient to exert any strong income effects. It seems that individuals think of the provision of a new service such as this one both in its physical sense of being something provided and in terms of its productive output.

Though this evidence is hardly conclusive, individuals who are considering policy interventions relating to noise regulation or reduction should expect that even "educated" answers to willingness-to-pay queries will exhibit a variety of biases. One bias in particular, noted by Acton, will be a tendency to anchor one's valuations. For any given individual, or for a class of individuals with like characteristics, the value of a noise reduction may be surprisingly insensitive to the amount that the noise level is reduced. People may think in terms of "getting rid of noise." Given limited familiarity with measures of noise, and/or the consequences of exposure to it, their valuations may not be responsive to what experts might consider to be quite extensive differentials in noise reduction. No doubt there will be other biases in survey assessments as well. The important point to realize is that such biases may exist.

This raises the whole issue of calibrating assessments, that is reinterpreting them to determine what people really would pay if they understood the ramifications of the choice.* An alternative procedure would be to ask individuals to compare their valuation of noise disturbance as determined by tradeoffs with other valued goods bearing similar characteristics. Clean air would seem to be a good example. What is done here is to employ another environmental contaminant, not money, as the numeraire good.

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*Such "calibration" is frequently proposed for refining the information people provide when they make probability assessments. It is well established, for example, that untrained individuals are likely to assess such distributions too tightly.

2. Willingness-to-Pay and the Determination of Noise Levels

The foundation of the willingness-to-pay approach is that we should balance total willingness-to-pay at the margin for increased noise levels against total willingness-to-pay at the margin to keep the levels down. A critical problem, of course, is that since noise disturbance can not be packaged and sold on an individual basis, as say can fertilizer or even solid waste; there will be no market transactions to provide information on willingness-to-pay. Indeed, as was argued in our previous section on the Production Process for Noise Disturbance, there is not individualized production either, at least not in the sense that the amount of disturbance one producer generates is independent of what other producers put out.

This absence of a market where consumers and producers meet to exchange noise disturbance creates a variety of problems. First, whatever procedures are determined to make willingness-to-pay assessments, there can be no guarantee that true values will be provided. Second, even if we had exacting knowledge of willingness-to-pay, so that we would know how much it should cost at the margin to reduce noise disturbance, we might not be able to translate this information into a regulatory procedure. Since noise disturbance is not an additive commodity, we can not know what each producer could do at the margin to reduce disturbance unless we knew what all producers are doing.

Before we discuss further the difficulties with these procedures, we had best be clear on the motivation behind willingness-to-pay itself. Our starting point is understanding that what we are attempting to do is reproduce an outcome that might resemble what the market could produce, could it function appropriately. We shall not be involved here in the intricacies of operation of regulatory processes. That is, we are restricting ourselves to the raw information about willingness-to-pay, not taking the logical next step of seeing how it will be employed.

Noise and Willingness-to-Pay

The fundamental assumption of this entire analysis is that a quiet environment, like apples and oranges and clean air, is a commodity that individuals value. Their preferences in this regard are made evident by their willingness to trade other valued commodities in return for a quiet environment. That we do not observe such trading operations at work, for the most part is an indication of the non-existence of markets in which noise reduction can be purchased on an individual basis. Indeed, for evidence that noise, or more precisely its absence, is a valued commodity we can look to individual consumers' purchases of noise proofing materials, as well as an array of behavior patterns that enable them to avert noisy environments. Our later analysis will devote substantial attention to individuals' possibilities for averting more disturbance and the ways that will affect willingness-to-pay assessments.

Willingness-to-Pay - Its Theoretical Justification

Economic markets that are working in perfect fashion automatically generate information on willingness-to-pay. It is merely the price on the market. Every individual will continue purchasing any good until his valuation of the last unit is just equal to the amount of resources that would be required to purchase it.

Public policy intervention comes under consideration when markets are not functioning appropriately. In the environmental sphere, such interventions take a variety of forms ranging from effluent charges, to prohibitions, to approved technologies, to standards, to subsidization of certain types of activities, and the list continues. Some of these interventions are designed to function on an automatic basis. Others must acquire information on the preferences of individuals and firms so effective levels can be set. For example, if standards are to be set, we will wish to find out how much individuals value noise pollution at the margin, and how much those who produce the noise value its continuance or increase.

Most of the interventions proposed are designed to reproduce an outcome that to a significant extent reflects the outcome that would be achieved if there were a functioning perfect market for the commodity. For reasons that will be deliberated at length below, the general efficiency condition is that for each type of noise that is received, the willingness-to-pay to avoid a marginal unit will just equal the willingness-to-pay to produce that unit (i.e., not be required to eliminate it).

This beautiful balance can only be achieved in traditional markets because the transactions are actually carried out. Those who receive the goods pay for them. Those who sell them must produce them. So long as no individual or firm can produce the good at less than its market price, so long as no consumer would pay more for the good than is currently being charged for it, it is evident that no rearrangement of resources relating to the production of that particular good can work to the benefit of all parties concerned.

In a world where efficiency is a goal, this same property should hold true for noise. For any particular element of noise disturbance, there must be an equilibrium in the costs to those who gain and lose from the disturbance. Here though the disturbance will not be individually conveyed. This implies that we must be concerned about the total of the prices that would be paid by all affected consumers. They are all simultaneous "purchasers." On the production side, we must look to the producer of the disturbance who can eliminate it at lowest cost. If the lowest cost of elimination is less than the total amount that could be extracted from all beneficiaries, then with appropriate side payments the disturbance could be eliminated to the benefit of all parties involved.

This is the familiar condition for efficiency in public goods provision. Let MRS_i represent the marginal rate of substitution of individual i of some other numeraire good for a particular type of noise disturbance. Let MC represent the least amount of the numeraire good that must be sacrificed to reduce the noise disturbance by one (small) unit. For simplicity, there is no reason why money itself can not be employed as the numeraire good. The efficiency condition is that

$$\sum_i MRS_i \leq MC \ .$$

If the sum exceeded MC, then we could charge each individual his MRS, and employ the resources secured to reduce the noise level by one unit.

3. The Right to a Quiet Environment - An Alternative Approach

The framework within which a valuation question is posed can frequently affect the answer. Once the question is raised, what is a certain reduction in noise worth to a specific individual, we admit to our willingness to violate what some might think of as a right. That right is the privilege to exist in a quiet environment. Those who would maintain this right might suggest that it should not be incrementalized away merely because the tallied willingnesses-to-pay to preserve it did not equal the willing payments of those who would like to generate noise.

If the issue is framed in this manner, some might argue that what is being debated is merely the benchmark from which payments for changes should be made. The point of initial distribution should be thought of as zero noise, or at least some level of low noise that would be clearly acceptable.

But more than an appropriate benchmark might be involved.* First, unless this is a most unusual policy situation, the benchmark will be used as the point from which to measure losses, and the point at which we see who will be involved in the market. But compensation is unlikely to be paid from the benchmark.

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*You do solve part of the nonconvexity problem if you look at what would happen if we had a zero benchmark. All of those firms or individuals who would reside in the now noisy area would be in to make their appreciation of quiet felt.

This is not a bad solution as a thought experiment. In practice, it could accomplish rather less than this, as those firms and individuals will not be present. What could be done, of course, would be to see who is residing in equivalent areas which happen to be quiet. The only danger with this "ceteris paribus" approach is that we would be unlikely to find conditions that are equivalent except for being quiet. For example, it is unlikely that there is any zone along a major highway where we can show how citizens appreciate silenced trucks and motorcars.

Without controlled experiments, it is unlikely that we will ever be able to determine with any great degree of precision what we would like to know: How much citizens who would be participating in the area if it were quieted would pay to preserve (or demand to give up) their quiet sanctum. The world just can not generate the data that we want. Any results that were extrapolated from regression data would have to be interpreted with great caution.

Assume that a relatively low benchmark is selected; it could be a noise that is never annoying or disturbing in any way. The use of such a benchmark as the starting point for policy deliberations is likely to work in favor of those who would prefer a quiet environment. (This favoritism could continue even if no compensation were paid for deviations from the benchmark.) More of their quiet-preferring friends will be around to have their preferences measured. Those who produce noise, however, would be underrepresented at the equilibrium established from a low noise benchmark Some of them would only bother to make their entry into the market if a relatively high benchmark were established, will not be around to register some positive willingness-to-pay at the margin.*

The second major problem with the benchmark approach is that it in no way takes into account the notion of the inviolability of a right. No one would suggest that a rapist who would pay more to rape a woman than the woman would pay to avoid the rape should have the opportunity to do so. Moreover, even if compensation were paid and charged, few individuals would suggest that this activity was acceptable. Neither would we like to allow individuals to participate in a lottery for giving up their heart, say to a rich man in need of a transplant. There may just be a feeling with society that some things which we may think of as rights should not be traded away. Even to put the question into the framework of willingness-to-pay may be degrading.

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*There is an interesting question, relating to the convexity issue, of how much a firm or individual who would like to see a rise in the permissible noise level will pay for increases until his entry level is reached. If he will be charged full value once he gets to his entry level, then he will reap no surplus later, and he should pay nothing. But if there will be less than full extortionary charges later, then his amount may be positive. To make this determination involves more or less a dynamic programming approach, with the payer trying to predict whether a higher level of noise is worth anything if it is still below the entry level.

This would represent an instance where we do not wish to let unhindered individual exchange operate. If we were forced to look for an analytic justification for this wish, we might find it either in relation to issues of distribution or externalities in general. Both of these are discussed in separate sections. The distribution issue is relatively straightforward. We do not like to see individuals subjected to what we consider unsatisfactory environmental circumstances just because they are poor.

The externalities argument is merely the fact that others care when you are subjected to noise. It may be because we are forced to share in some of the costly consequences of that noise infringement. Alternatively, we may just not like the idea of individuals being subjected to noise.

Although the externalities and distributional arguments may address the reasons that we do not want individual exchange to predominate in these circumstances, they also may not predominate. The explanation may be much closer to the rape or life sacrificing cases. There are certain rights or amenities that independent of analytic argument we do not like to see sacrificed. If this argument is accepted, the only way the willingness-to-pay approach could be implemented would be to ask: How much would you pay to never be asked the question how much you would be willing to pay to accept a certain amount of noise. Convolutions such as this start to engage us in the type of paradoxes that so excited philosophers at different periods in the past. Perhaps it is best to merely recognize that not all parties will accept a willingness-to-pay approach, and that the arguments against it are not necessarily frivolous.

C DEFINING THE EFFICIENT OUTCOME

1. The Efficient Outcome With Noise Averting Activities

Assume for purposes of simplest illustration that all noise disturbance was produced by a single source and inflicted its external diseconomies on a single recipient. For purposes of discussion, let us employ the present noise level, N_0, as a benchmark. The cost to the noise producer of reducing noise below this level is C(N). The consumer would be willing to pay something to have the noise level reduced below N_0. Let us indicate this amount by B(N). The lower is N, the greater will be both C(N) and B(N).

If the only variable subject to manipulation were N, and if distributional considerations were ignored, the noise level would be lowered (or raised) to that point where the sum B(N) - C(N) is the greatest. Taking the appropriate derivative and setting it equal to zero, the efficiency condition is simply:

$$B'(N) = C'(N) ,$$

which can be interpreted that the marginal benefits from further noise reduction equal the marginal costs imposed on those who must reduce their noise.

A Model with Noise Averting Behavior

Matters are complicated just a bit if there is the possibility of noise averting expenditures or activities. Represent these activities as A. These activities will be undertaken by consumers, perhaps staying away from a traffic-noise plagued apartment during rush hours, or purchasing an air conditioner. The consumer now reaps a gain that reflects both the noise level and the averting activities that he undertakes. Represent his initial level of averting activities as A_0, with initial noise as N_0. The gain can be written G(A,N), a measure which arbitrarily puts $G(A_0,N_0) = 0$. The lower is N, the greater the value of G(A,N). The relationship with A is not monotonic however. Early averting activity for any particular noise level may improve the situation of the consumer. But after some point, the additional benefits of averting activity will be more than outweighed by the costs of undertaking it. It is assumed in this analysis that income effects are not significant; therefore G(A,N) can be defined independently of any charges for changes in A or N.

In a world with noise averting behavior, the equivalent to the B(N) function defined previously is G(A,N). The procedures for defining the efficient outcome are also equivalent. What we wish to maximize is the total net benefits to the consumer and noise producer. That is, we wish to maximize G(A,N) - C(N). In this analysis we shall employ dollars as the metric for which both benefits and costs are measured. This would imply that G(A,N) can be readily interpreted as the consumer's valuation of a particular A,N pair. We shall discuss in the section that follows the way these valuations can be converted to willingness-to-pay calculations for reduction in noise disturbance.

The conditions that determine the efficient combination of noise level and averting actions are readily derived by differentiating G(A,N) - C(N) with respect to each of A and N, and setting the derivatives equal to 0. This yields

$$G_1(A,N) = 0$$

and

$$G_2(A,N) = C'(N) .$$

The first condition is that averting activities should be neither increased nor decreased if the object is to reduce the implicit costs of the noise and activities to avert it. The second condition is that given a corresponding optimal level of aversion activities, the noise level should be adjusted so that willingness-to-pay for further reductions just equals marginal cost of further reduction. (There are some second order conditions, of course.)

This result suggests both the strength and weakness of a willingness-to-pay approach when averting activities can play a significant role. The strength is that even in the presence of possible averting activities, the efficient outcome when regulating an external noise disturbance is that the marginal cost of reducing the noise equals the marginal willingness-to-pay to avert it.

The weakness is that deducing willingness-to-pay for non-marginal noise reduction on the assumption that averting behavior will not change will lead to incorrect assessments. The efficiency condition that marginal willingness-to-pay for further noise reduction just equals the marginal cost of such reduction only holds when the level of averting behavior has been optimized as well. The next section discusses ways to define willingness-to-pay for noise reduction when averting behavior is explicitly allowed to vary.

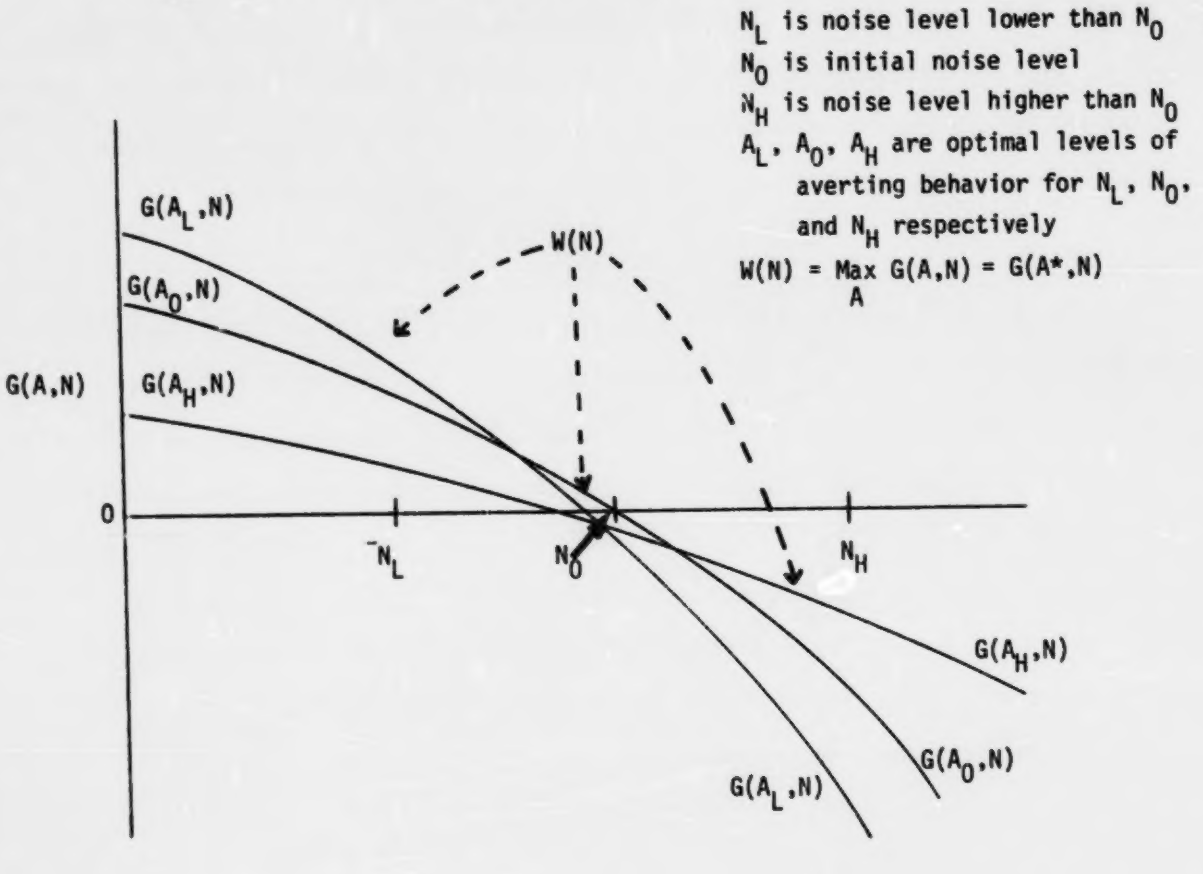
Willingness-to-Pay With Averting Behavior

Assuming that individuals would respond honestly, and accurately, what question would we like to ask them about willingness-to-pay? The appropriate question is the following:

> Allowing yourself to alter your averting behavior in response to changes in the noise level, how much would you be willing to pay to lower the noise level N?

The relationship of this question to the above equations is now evident. We can write $A^* = \max_{A} G(A,N)$, which defines A^* as a function of N. The willingness-to-pay function now becomes $G(A^*,N)$, where the first variable is understood to bear a functional relationship to the second. This whole function might be written $W(N) \equiv G(A^*,N)$, where $W(N)$ represents willingness-to-pay for achieving any particular noise level. The process can be best understood with the aid of a graph.

Fig. 2.3. Willingness-to-Pay With Averting Activities


N_L is noise level lower than N_0
N_0 is initial noise level
N_H is noise level higher than N_0
A_L, A_0, A_H are optimal levels of averting behavior for N_L, N_0, and N_H respectively
$W(N) = \max_{A} G(A,N) = G(A^*,N)$
G(A,N)
$G(A_L,N)$
$G(A_0,N)$
$G(A_H,N)$
W(N)
0
N_L
N_0
N_H
$G(A_H,N)$
$G(A_0,N)$
$G(A_L,N)$

The willingness-to-pay curve, $W(N)$, is now represented by the upper envelope curve. The efficiency condition is that

$$W'(N) = C'(N) \; ,$$

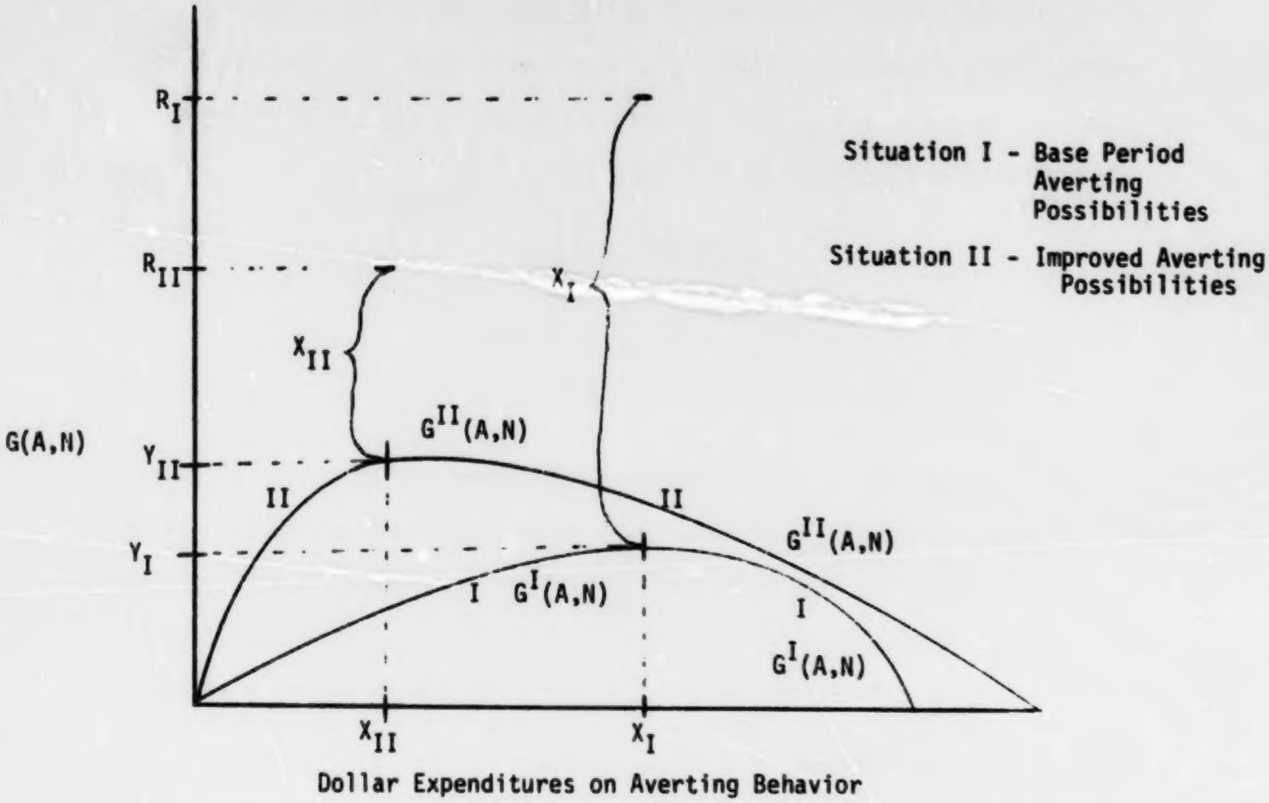
which is the standard notion that willingness-to-pay should be set equal to the marginal cost of improvement. There are at least two things to note about the $W(N)$ function. First, except for noise levels close to N_0, it lies everywhere above the curve for $A = A_0$. The way to interpret this is that the value of noise reduction is greater if other actions can be changed as well.

This result also applies when considering possible increases in noise. Being allowed to engage in averting behavior reduces the consequence of the loss. In sum, the curve of gain (or loss) from noise reduction (increase) with the possibility of changes in averting actions lies on or above the curve $G(A_0,N)$ which assumes no alterations in averting actions are possible.

Averting Actions and Loss from Effective Noise

The second point may be a little more contrary to intuition. The slope of $W(N)$ over some range can be greater or less than the slope of $G(A_0,N)$. What is interesting is that for the same noise level, new or superior averting capabilities may lead to less total averting behavior (measured in some units such as dollar expenditure on averting behavior), and what is perhaps more surprising, possibly a higher level of effective noise. Since it is more contrary to intuition, let us illustrate the situation where improved averting possibilities lead in fact to an efficient outcome where the effective noise level is increased, not decreased.

Fig. 2.4. Effective Noise Levels With Alternative Averting Possibilities



In old situation I, the optimal level of expenditure on averting behavior was X_I. This yielded a total gain of Y_I. Y_I can be broken down into component parts. One part is the loss from the implicit costs of averting behavior. This has already been identified as X_I. The other component is the cost of the noise itself as indicated by willingness-to-pay. But the noise component is modified by the level of averting behavior. What we are worried about therefore is not the absolute level of noise disturbance, rather the noise disturbance as perceived by the individual receiver. This received noise disturbance might be referred to as the effective level of noise. We shall refer to the gain from the reduction in the effective level of noise (from some initial reference level) as R. For the old situation, it would be R_I. This is merely addressing the G(A,N) function in a separable and additive form.* That is,

$$G(A,N) = H(A,N) - E(A),$$

where

$$H(A,N) = R \quad \text{and} \quad E(A) = X.$$

In new situation II, there are new and improved averting technologies. The $G^{II}(A,N)$ curve lies above the $G^{I}(A,N)$ curve thus representing this gain. Yet, in the situation illustrated, not only is expenditure on noise averting behavior less in situation II, but the effective level of noise reduction is also lowered. This noise reduction, from the equations above, is given as

$$R = G(A,N) + X .$$

In the diagram, it is shown that R_I is greater than R_{II}. The initial situation had more effective noise reduction. What this implies more generally is that no firm conclusions can be drawn about the relation between advancing technologies for noise reduction (or noise control) and the optimal levels of effective noise.

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*This procedure may be particularly acceptable here since N is fixed. The only requirement is that the two contributions of A, as a cost in terms of influenced behavior, and in terms of reducing effective noise level, be quantifiable in the same units.

This is, of course, a special situation. Generally, we would expect that as improvements are achieved in averting mechanisms, effective noise levels will be reduced.* What the analysis does illustrate is that the whole issue of assessing the damages from noise is a most complex one. Our intuition can frequently lead us astray.

It also stresses the need to look at the measurement of noise disturbance from the standpoint of the individual receiver. Purely physical interpretations of noise disturbance, and especially those measured at the source, can not monitor what policymakers should be after: the amount that the noise disturbs its human receivers.

The Implications of This Analysis

The implications of this analysis flow in two directions. First, even assuming that those who suffer from noise could effectively coordinate themselves to engage in an optimal level of noise averting behavior, no firm conclusions about willingness-to-pay can be drawn merely by observing present levels of suffering from noise. To make such a determination, we would have to have information on marginal costs of noise-averting strategies that are not being undertaken. If such strategies merely involve a foregone intensification of present strategies, monitoring marginal costs will be a pretty routine process. But they may involve a switch in a number of actions, in which case empirical determination of marginal costs will be extraordinarily difficult.

Second, if EPA finds itself in a position to regulate noise and/or noise averting behavior, it should not conclude that if there are advances that make it less expensive to reduce or avert noise that these will automatically lead to lower optimal levels of noise. Let us say that a new noise proofing material is developed that can achieve 95% of the level of noise reduction of present standard materials at 20% of the cost. If further noise reduction were desired beyond that offered by the new material, it would be necessary to revert to traditional methods. It would seem quite reasonable for society to opt for the much cheaper new technology, and make a slight sacrifice in terms of the level of effective noise for a substantial savings in expenditure.

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*The example from the text might occur as follows. Base period reduction of 20 units of disturbance at cost of $1,000. New technology permits 18 unit reduction for $300, with further reduction very expensive and not worth it. The improved technology leads to an efficient equilibrium where there is less reduction in noise.

To sum up, optimal levels of noise, as determined within a willingness-to-pay model depend both on activities available to avert the noise and the cost of reducing the noise itself. If there are closed pedestrian malls alongside major traffic arteries, then it may be less important to reduce traffic noise. If soundproofing for homes is relatively inexpensive, less stringent standards should be imposed on noise-generating facilities in residential areas. If inexpensive procedures are developed to reduce the noise produced by trucks and buses, desirable levels for traffic noise are likely to be reduced as well. If a city layout is such that individuals can readily escape from noisy areas, then it may be less important to reduce noise disturbances in those areas where they are significant.

Collective Action on Averting Behavior

This analysis assumed that individuals would be able to coordinate themselves appropriately to achieve an efficient level of averting behavior for whatever noise level happens to pertain. In general this assumption will be valid, since most forms of averting behavior can be undertaken individually.

Each individual can weigh his own costs of protecting himself against noise. If these are the total cost, and if he is the total recipient of the benefits, an efficient outcome will be achieved. Moreover, if there are many recipients of the noise acting independently, strategic manipulation of levels of averting behavior will not prove profitable. If say EPA charges all noise producers the summed willingnesses-to-pay to avoid their noise output, it would not pay any single recipient to reduce his averting behavior thereby increasing (most likely) his willingness-to-pay and leading ultimately to a reduction in noise level. His willingness-to-pay in itself would change the sum for all recipients by but a tiny percent. His benefit from the reduced noise level would be minimal, yet he would bear all of the burden of his suboptimal level of averting behavior.

A concrete example makes the point clearly. Think of an uncoordinated community of individuals disturbed by traffic noise. EPA is going to discover the losses imposed on the community by traffic, and then regulate appropriately. It would surely not be in the interest of any individual to leave his window open just to alter the EPA total, and therefore ultimately the traffic noise.

If the community could organize itself, matters might be different. They could agree as a general policy to leave windows open. Each would be contributing to a collective good: a higher marginal valuation on noise produced.

Not all forms of averting behavior will be individually purchased. For example, placing trees at roadside along one's property may help shield noise disturbance for all. Citizens as a whole might prefer a situation where everyone planted trees, but in the absence of coordination, no such trees would be purchased. A perhaps more compelling example would relate to buildings that are subjected to much public traffic. No one individually would have much of an incentive to emplace noise insulation.

Government regulation of noise disturbance should recognize that the structure of productive possibilities may be such that there will not be appropriate incentives for noise recipients to engage in efficient levels of certain averting activities. If the government can not develop other policy measures to insure that such activities will be undertaken, it may wish to pursue a more intensive course in the regulation of noise.

2. Noise and Location in a General Equilibrium Model

Economists have traditionally been quick to assume that price systems will produce stable and globally efficient outcomes in problems involving external diseconomies. Recently the problem of nonconvexity of the recipients' loss functions has received attention. It has been recognized that firms and consumers may have the opportunity to shut themselves down and remove themselves from the presence of the externality,[*] and from further marginal damage.

Noise pollution involves a locational problem that vaguely suggests the shutdown possibility, but really a quite different analytic property applies. The situation is such that traditional general equilibrium models do not apply, but the price system will function effectively nevertheless. The genesis of the problem is that individuals consume not differing quantities of lots at different locations but rather one location or another. (We abstract from the situation where individuals purchase two or more houses, which would complicate the analytics but not change the basic result.) The traditional indifference curve analysis no longer pertains. The individual's consumption choice, assuming that there are but two locations, is between two points, not a continuum of possibilities.

But other portions of the general equilibrium model continue to apply. Each point will have associated with it a price. The hope is that a decentralized price system can be established that allows each individual to select his most desired purchase and through that very process generates an efficient outcome. A numerical example will make the structure clear.

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[*] See David M. Starrett and Richard Zeckhauser, "Treating External Diseconomies - Markets or Taxes?." in Statistical and Mathematical Aspects of Pollution Problems, John W. Pratt (ed.), Marcel Dekker, Inc., New York, 1974, pp. 65-84, for further discussion of this issue.

Optimal Assignments of Individuals

$$\begin{array}{llccc} & & & \text{Location} & \\ & & M & E & H \\ & I & 400 & \boxed{250} & 0 \\ \text{Individual} & II & \boxed{300} & 80 & 0 \\ & III & 290 & 120 & \boxed{0} \end{array}$$

Here M is the quietest location, E second quietest and H the noisiest. The numbers in the matrix represent the amount that each individual would pay to have that location rather than H. For example, individual II does not like E much more than H, but finds M much more pleasant than H. In the particular numerical example under consideration, the three circled numbers give the optimum assignment, with I at E, II at M, and III at H. The total value of the allocation is 250 + 300 + 0 = 550. By comparison, with I at M, II at E and III at H, the total value would be 480.

It is, of course, quite possible that the individuals do not even agree on the ordering among the outcomes. Because noise is a multi-dimensional commodity, this might occur even though noise by itself were the only characteristic of importance. Some individuals may not like noise at night, others during the day. Some may feel most strongly about peak decibel level, others may be more concerned with the average. Some may object to high pitched noises, others may object to traffic noise, etc. But differences in ordering are more likely to reflect other factors such as convenience, a very personalized commodity, or other local amenities not related to noise.

What then of our problem, will a price system lead to an efficient outcome? First, we should assure ourselves that there is an efficient outcome. There surely is, for this is merely the job assignment problem that is well known in operations research.* In that instance, the objective is to find the assignment of jobs that maximizes the total payoff to the group, where their valuations are just added together. Here we wish to associate individuals with locations.

It is worthwhile noting, before moving on to the question whether the price system will support the optimal assignment, that this procedure is perfectly general and will work if there are many individuals and many spots available at each location. Moreover, the total spots may exceed the number of individuals. The job assignment equivalent to this situation would have many different openings for the same position (or to keep matters particularly pure, many replications of the same position).

Willingness-to-Pay and Optimal Levels of Noise at Locations

If we had collected information on willingness-to-pay of individuals with different characteristics, then in theory we would optimize noise levels in the following manner. There are three (an arbitrary number) different types of individuals, with willingness-to-pay for noise reduction schedules of the form $W_a(N)$, $W_b(N)$, and $W_c(N)$. (These schedules can be calibrated from any arbitrary benchmark, for simplicity let us say a noise that is never annoying.) The individuals are at the locations in the numbers:

	Main Street	Elm Street	High School
Type a	M_a	E_a	H_a
Type b	M_b	E_b	H_b
Type c	M_c	E_c	H_c

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*See pages 183-184 in Harvey M. Wagner, Principles of Operations Research With Applications to Managerial Decisions, Second Edition, Prentice-Hall Inc. Englewood Cliffs, New Jersey, 1969. This is a variant of traditional transportation problems.

It should be understood that these numbers need not suggest that they spend all their time there. Some individuals could be allocated fractionally to two or more locations. Similarly, if as expected, noise varies over the times of day, what is called here location should be thought of as a location-time pair.

Now it may turn out that the cost of reducing the noise on Main Street is greater or less, depending on what is done on Elm Street. For example, if a cheap way to reduce incidence on Main Street is to reroute trucks to Elm Street, we would expect these cross-effects to work against us. On the other hand, once a noise-muffling system is installed on autos in town, there is no additional cost of quieting things down on supplementary streets. To deal with a situation where there are multiple locations, the analysis is quite parallel, it is just that the cost function takes the form $C(N_M,N_E,N_H)$; i.e., the cost of noise levels across the city must be computed simultaneously.

The noise levels across the city must be optimized simultaneously. Employing the same procedure as before, where the objective is to maximize willingness-to-pay for noise levels less the cost of achieving them, the objective function is

$$Z = \sum_{j=a,b,c} M_j W_j(N_M) + E_j W_j(N_E) + H_j W_j(N_H) - C(N_M,N_E,N_H) \ .$$

Three equations make up the efficiency conditions. For the noise on Elm Street the efficiency condition is

$$\frac{\partial Z}{\partial N_E} = E_a W_a'(N_E) + E_b W_b'(N_E) + E_c W_c'(N_E) - \frac{\partial}{\partial N_E} C(N_M,N_E,N_H) = 0 \ ,$$

with equivalent conditions being defined for the other locations. In the special case where the cost function can be written as a separable function of the costs of achieving noise levels in each location, the last term in the efficiency condition then can be written $C'(N_E)$. The interpretation is the summed willingness-to-pay for further noise reduction at each location equals the marginal cost of further noise reduction at the location.

Changing Locations and Willingness-to-Pay

This whole analysis has assumed that individuals will not shift their locations after noise reduction. But that may not be the case, so there may turn out to be more a's on Elm Street and fewer at the High School, etc. Recognizing the possibilities for "moving around" greatly complicates the task of computing willingness-to-pay. Merely surveying those who are presently residing in an area may not be sufficient. To take explicit account of changes in location is the purpose of the general equilibrium analysis.

Rent as an Indicator - Sometimes Appropriate, Sometimes Not

It is sometimes alleged that a way to assess the gains from improving environmental amenities is to determine what happens to rentals. This is incorrect, as a simple example will make clear. Let us assume that we have two residential areas. One is closer to town but noisier. The more distant area is sufficiently quieter that the noise factor more than balances the convenience factor; the quieter residential section commands a rent differential.

A measure is now undertaken to reduce the noise in the close-by area, thereby raising its relative attractiveness. This will reduce the rent differential between the two residential sections. The total rentals within the system will diminish.* The missing factor is the consumer surplus that the renters receive as the noise level is reduced. It should be counted as a benefit to be added in with the gains in rentals. (Consumer surplus will count in quite the opposite way, that is be reduced, if the noise reduction takes place primarily in the area that is already commanding the scarcity rental.)

There is much confusion on the rental issue, and it is important to understand that willingness-to-pay determinations may be profitably secured by inquiring about rents. If a noise reduction on Elm Street were under consideration, we might inquire of the Elm Street tenants how much additional rental they would be willing to pay at a maximum in return for such a reduction. The answer to this question, assuming that it was honestly and accurately provided, would tell us about the willingness-to-pay of those presently living in the area. It would be an appropriate guide to efficient noise-reduction decisions.

Note that this determination may differ significantly from what happens to rentals when a noise reduction is undertaken. If present residents were all the possible tenants in the world, and if the rental market were competitive, then the rise in rent would equal the willingness-to-pay of the individual who valued the noise reduction the least. All the remaining tenants would reap additional consumers' surplus from the noise reduction; that is, they would reap a gain in overall welfare since they would be charged less for the noise reduction than the amount they would have been willing to pay for it.

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*If there were other individuals in the world, one could argue they could come in and bid up the rent. It is true that if this area is small relative to the rest of the world, and if it is the only one undergoing noise reduction, rentals will adjust to reflect any environmental gains.

From the standpoint of EPA, however, this form of small sector of a large system analysis will not likely be relevant. If noise standards or other noise regulating activities are to be undertaken, it is likely that they will be imposed in many areas. Consumers surplus gains or losses will not be wiped out by competing with some grand world.

This situation, idyllic for the renters, actually will not come to pass. Rents are likely to be bid up by more than the minimum valuation as outsiders are enticed into the now quieter neighborhood. Consumers' surpluses for those forced out are likely to be negative. Most of those who still reside will be reaping a positive gain, as will the neighborhood newcomers. Two general conclusions are evident.

1) Merely asking the present residents how much they would pay to quiet the neighborhood leaves aside the important information of how much outsiders who might move in would pay.

2) Merely observing rental differentials between quiet and noisy neighborhoods, or the change in rentals that occurs when a neighborhood changes its level of noise disturbance does not reveal willingness-to-pay. And information on that quantity, after all, is the building block of efficiency determinations in this area.

Using Willingness-to-Pay When Individuals Change Locations

In the next section we present a simple numerical model which illustrates the way the gains to society as a whole should be computed when we must value a noise reduction within a general equilibrium model. The numerical results show in essence what is the appropriate way to value any reduction in noise, when noise is a localized disturbance, and where individuals choose neighborhoods on the basis of the combination of rental levels and environmental amenities. (It should be understood that rentals implicitly applies to owner-occupied housing as well. The "rents" for such are total monthly charges net of capital accumulation for the owner.)

First, survey all individuals to see how much they would pay to live in each possible location. The model suggests that present location assignments have been optimized to give society the highest achievable value in terms of summing up the residents' valuations for where they live. This allocation is readily determined, as we shall show later, by letting the price system function in a manner that permits rents to reach competitive levels.

Second, survey all individuals to see what would happen to their valuations in response to possible changes in the level of noise disturbance at one or another location. Then determine the manner in which individuals will shuffle their locations in response to the reduced noise disturbance and changed valuations. Or to say the same thing in different words, determine the new highest achievable value for the society as a whole. The summed willingness-to-pay for the noise reduction at that location will equal the difference between the present highest achievable value, and the one for the world before the noise reduction.

If the cost of the noise reduction is any amount less than this crucial difference, then it would be inefficient to forego the reduction. (Efficiency here is understood in terms of Pareto optimality. For a situation to be inefficient, there would have to be an achievable distribution of charges for the costs of reducing a noise disturbance such that assessing the charges and carrying out the reduction made some individuals better off and no individuals worse off.) If the cost of the noise reduction were greater than the crucial difference, then undertaking the reduction can not be to the benefit of all parties concerned; it can not represent a move to a Pareto superior position.

The analysis below just looks at a noise reduction of a particular magnitude. In a policy context, there may well be some latitude to determine the extent of the reduction in disturbance. The ability to make adjustments in the magnitude of the reduction in no way complicates the apparatus for calculating efficient outcomes. We would just have to compute the gains in total value for in between levels of reduction. Reductions would be continued until the marginal cost of further reduction just equalled the marginal gain in the total valuation to society for the optimal allocation of locations. The exact procedures can perhaps be better understood with the aid of a numerical example.

A Simple General Equilibrium Example

Our simple general equilibrium model involves three locations, each with a capacity for three tenants, and nine individuals. Location A is generally considered to be the most attractive location, a factor which reflects matters such as convenience and cleanliness as well as the noise level. B is the second most attractive; on average it receives lower valuations by individuals. C is the least attractive.

To secure the valuations of the individuals for the three different locations, we employed a computer-based random number generator. The values for location A were chosen from the uniform distribution with endpoints at 100 and 200; those for B over the interval from 50 to 150; and those for C from the interval 0 to 100.

		Locations		
		A	B	C
	1	121.27	[✓ 146.33]	36.52
	2	102.13	[✓ 84.11]	35.52
	3	[✓ 156.13]	117.07	47.22
	4	[✓ 129.72]	53.36	2.65
Individuals	5	135.63	89.97	[✓ 69.13]
	6	105.07	[✓ 108.27]	53.98
	7	149.43	110.76	[✓ 69.69]
	8	121.32	100.75	[✓ 62.63]
	9	[✓ 169.00]	50.31	30.87

The optimal location algorithm assigns three of the nine individuals to each of the three locales. As shown by the circles, it places individuals 3, 4 and 9 at A; 1, 2 and 6 at B; 5, 7 and 8 at C. The total score over all the locations is 995.02.

The Optimal Assignment Algorithm

Before turning to the critical policy question, what will a noise reduction be worth, it is worthwhile to observe the way the optimal assignment procedure is conducted. It turns out to follow a straightforward market simulation. This implies that real world markets could (and to the extent that there are not imperfections in them do) operate in the same manner. Initial prices, the $p_i(0)$'s, are set for the three locations. Good starting points are expected values (150, 100, 50 in this example) or actual averages of valuations drawn from the sample. Individuals are then "told" to identify their highest value location net of price. Individual 3, for example, gets net values of 6.13, 17.07, and -2.78. Then each individual is assumed to demand his highest value location. This is the location where he would get the highest net payoff if he had to pay the "rental price." Individual 3 demands location B. Excess demands, the D_i's, for the locations are computed by adding up the number of individuals who want each and subtracting out the spaces available. It is then time to determine a next round of prices to diminish these excess demands. The algorithm employed was

$$p_i(t+1) = p_i(t) + \delta D_i \ ,$$

where i indexes the locale and δ is some arbitrary small value. The program converges swiftly to the optimal allocation.

Valuing a Reduction in Noise Disturbance

Now that we understand how individuals are optimally allocated (or given the pricing algorithm allocate themselves) to locations, we can compute how much a noise reduction is worth. To illustrate, let us inquire what it is to have a noise reduction of say ten points in the community noise index at location A. There are no changes in noise disturbance elsewhere. To give a simulated answer, we added a random number to individuals' original values for location A. The random numbers added were chosen from the uniform distribution over the interval 0 to 100. (Individual 9 had 30.72 added to his score, by way of example.)

If the location assignments had stayed as they were, that is if there were no possibility for rearrangement, the total score would increase to 1063.98. (Individuals 3, 4 and 9 gained 68.96 between them.) This implies that if a willingness-to-pay survey were taken of the individuals in the location that would receive the noise reduction, the total assessed gain would be 68.96.

		Locations		
		A	B	C
	1	218.6047250000	146.3306010000	36.5172801000
	2	139.6452770000	84.1127996000	35.5243602000
	3	159.2590500000	117.0665000000	47.2205200000
	4	164.8370020000	53.3606901000	2.6460849900
Individuals	5	172.1546650000	89.9669600000	69.1291599000
	6	162.2032720000	108.2716000000	53.9786301000
	7	217.4936430000	110.7551000000	69.6862202000
	8	169.5423200000	100.7546000000	62.6318402000
	9	199.7236290000	50.3099799000	30.8650200000

Reallocation possibilities increase this gain. Individuals 2, 3 and 7 shift locations. The total score increases to 1121.01. The social return from this particular reduction in noise is 125.99 = 1121.01 - 995.02.

It is worthwhile to note that an extrapolation of standard pricing algorithms will support these equilibria. That is, if every individual looked at the prices charged for the different locations and went to the location offering the highest return net of price, a socially efficient allocation would be achieved. Moreover, equilibrium prices can be determined by programs that produce marginal price adjustments in response to excess demands. The prices for the three locations before the noise level were 87, 48 and 0. After the noise reduction, the prices changed to 147, 53 and 0. (The expected values for the prices before the random numbers were drawn were 100, 50 and 0 before reduction, and 150, 50 and 0 after reduction.)

Implications of the General Equilibrium Model

What lesson should be drawn from all of this? First, if rental prices adjust in a traditional manner to changes in environmental amenities, efficient equilibria will be achieved despite the discrete nature of the opportunity sets for individuals. Second, willingness-to-pay surveys that attempt to assess the value of reductions in noise levels should look not just to the individuals resident in the area, but future potential residents as well. Surveying merely the first group will always give a lower bound on the value gained should noise be reduced. (This argument is made independent of any distributional considerations.) Alternatively, if a relaxation in noise level is being considered, surveying only those who are in the geographic area that will suffer will provide an upper bound on the amount of loss. These two results together offer a general principle. If willingness-to-pay assessments are addressed without regard to possible changes in location, the policy conclusion will always be a bias toward the status quo.

There is a further implication of the general equilibrium model that is almost a byproduct of its overall structure. The control of noise disturbances should be a localized phenomenon. It will not in general be optimal to have the same level of noise disturbance in all locations. Neither will it be optimal to have all producers of like noise, say all truckers or operators of factories, to reduce their noise disturbance to the same level. The level that will be optimal in each instance will depend on the numbers of people who will be subjected to the noise, the way they will feel about it, and what other individuals become involved with the noise should its level be changed.

Just knowing that noise levels should be responsive to local conditions gives us no final information as to how responsibility for noise control should be shared among different levels of government. But it does tell us that we should be hesitant before extrapolating results derived from willingness-to-pay surveys conducted in Boston to all other metropolitan areas, or indeed to other sections of Boston.

3. Putting Willingness-to-Pay to Work in a Dynamic Context[*]

Traditional willingness-to-pay approaches start at the present situation. This presents a variety of difficulties:

1) This is an acceptable procedure for looking at local changes, but not those that are global. If substantial changes were being considered, then there might be some parties who would benefit or be hurt, yet who are not represented in the present situation.

2) There may be inertial costs associated with the present situation. Individuals or firms may have already accommodated to extant rules and regulations. This raises problems of both equity and efficiency.

3) The present situation is likely out of equilibrium. Therefore all of the values that are observed or prices in the market may not be good indicators. This would imply that we could only extrapolate to a limited extent.

4) Individuals or firms may have already made defensive expenditures, thinking matters will not change significantly. This may raise questions of compensating for past inequities, or of continuing present situations even if they are not fair.

The difficulty is made particularly evident if we look at two situations, one where defensive expenditures have already been made, so costs of continued high noise levels are rather minimal. Yet in a parallel situation where individuals may not have yet soundproofed their house or purchased air conditioning, let us say, then it will be seen as more pressing to reduce sound levels. The analysis that follows shows how costs of moving from the present situation should be taken into account in the efficient regulation of noise disturbance.

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[*] Neil Goldman provided valuable assistance with the mathematics and calculations in this section.

Most traditional analyses invoking willingness-to-pay considerations are employed to determine a static optimum. A few look to optimal long-run dynamic relationships, in which case costs and benefits of alternative strategies are cumulated via some discounting procedure. Recognizing that the limitations imposed by starting conditions may be significant, real world policy prescriptions should rely on dynamic assessments.

Residential locations, traffic flows, noisy equipment and noise averting behaviors are all in place and have been optimized given current regulations and present noise patterns. Moreover, willingness-to-pay determinations as assessed through contemporary surveys all reflect the present situation. If we could start over, all of these parameters might take on substantially different values. But if there are significant costs to changing the parameter values from those that presently exist, that fact should be recognized in any long-run analysis.

If buildings are already soundproofed, it is less desirable to reduce the noise from traffic flowing around them. If traffic patterns, hence commercial and industrial locations, are already established, it will be more costly to change traffic flows to reduce the incidence of noise on human beings. If noisy washing and drying machines are in place, it will be more costly to reduce effective noise levels from such appliances. These are all categories of problems with which we are likely to be thoroughly familiar. Costs of transition to superior equilibria must be recognized. To illustrate, using our previous notation, let us assume that initial averting and noise levels are A_0 and N_0, where A_0 has been selected to maximize $G(A,N)$, given N_0. The per period gain of continuing at this level is $G(A_0,N_0)$, which has arbitrarily been defined to be 0.

Now we recognize that because of the existence of uncorrected market failures in the past, these levels may not be appropriate. What new levels should be invoked? Represent the transition costs to a new level of averting activity as $S(A|A_0)$ and the transition to a new level of noise as $T(N|N_0)$. (Assume that the cost of getting to a new level is independent of the speed with which it is achieved, which would imply the transition would be immediate.) The object then is to find optimal levels A** and N**. (The double asterisk distinguishes these optimal levels, where transition costs are included, from the optimal levels determined with zero transition costs, for which a single asterisk is used.) The costs associated with noise and its control include both transition costs as well as the period costs of averting behavior and noise reducing behavior. Employing a period discount rate of r, what we wish to maximize is:

$$\left[\sum_{t=0}^{\infty}(G(A,N) - C(N))/(1+r)^t\right] - S(A|A_0) - T(N|N_0)\ .$$

A Numerical Example

How do these optimizing conditions work out in practice? The best way to give a good intuitive feeling for the answer is to work out a simple example. The properties of the $G(A,N)$ function are perhaps most simply understood if we break it into two parts. The first, $H(A,N)$, reflects the consumers' actual feelings about the averting actions-noise level pair. Thus $H(A,N)$ can be interpreted as a willingness-to-pay figure for an effective level of noise. The second part, $E(A)$, relates how much it costs to undertake averting behavior. For the purposes of this example, then we write

$$G(A,N) \equiv H(A,N) - E(A) .$$

Define a function $H(A,N)$ to represent the per period gain or benefit (it could be negative) from being at a level of averting activity A and at a noise level N, as opposed to some arbitrary reference levels. The period costs of averting behavior and noise reducing behavior are defined as $E(A)$ and $C(N)$, respectively. Ignoring transition costs to new levels of A and N, optimal levels A^* and N^* are determined by maximizing period returns to noise averting behavior and noise reduction. Employing a period discount rate of r, the function to be maximized with respect to A and N is:

$$(1) \qquad \sum_{t=0}^{\infty} \frac{1}{(1+r)^t}[H(A,N) - E(A) - C(N)] .$$

Transition costs are now introduced and their effect on the optimal values of A and N is determined. The initial noise level N_0 is taken to be a non-optimal level (greater than N^*) without transition costs, and A_0^* is the optimal value of A corresponding to this fixed value of N, determined from equation (1) with $N = N_0$. We then represent the transition costs to a new level of averting activity as $S(A|A_0^*)$ and the transition costs to a new level of noise as $T(N|N_0)$. It is assumed that the cost of getting to a new level is independent of the speed with which it is achieved. This implies that the transitions are immediate and involve "one time only" costs. New optimal levels A^{**} and N^{**}, are determined by maximizing

$$(2) \qquad \sum_{t=0}^{\infty} \left\{ \frac{1}{(1+r)^t}[H(A,N) - E(A) - C(N)] \right\} - S(A|A_0^*) - T(N|N_0) \equiv F(A,N) .$$

For ease of analysis, the scaling for the variables A and N in the function $H(A,N)$ should have the properties that: As A increases with N constant, $\partial H/\partial A$ decreases, and as N increases with A constant, the absolute value of $\partial H/\partial N$ increases, and that of $\partial H/\partial A$ increases. In other words, as the level of noise averting behavior increases with noise level constant, the marginal gain, or decrease in damage, decreases and as the noise level increases, with a constant level of averting behavior, the marginal damage from noise increases. Also as the noise level increases, the marginal gain from an increase in averting behavior increases. Moreover, neither $E'(A)$ nor $C'(N)$ should be decreasing. If the world is well behaved, it should be possible to scale A and N so that all these conditions are met. (One possibility would be to measure both A and N on a dollar cost basis.) We shall employ the above-mentioned properties in structuring our numerical example, where both the level of averting behavior and the noise level might be thought of as involving physical units.

Note that we should expect A** and N** to satisfy

$$A^* < A^{**} < A_0^* \quad \text{and} \quad N^* < N^{**} < N_0 .$$

Clearly, the smaller the transition costs, the closer the new optimal levels will be to A* and N*.

A Numerical Example

The entire procedure might be more easily understood with the aid of particular functional forms and a numerical example. Let

$$H(A,N) = K - D(N-A)^2$$
$$E(A) = A^2$$
$$C(N) = (30-N)^2$$

where K and D are constants. Note that we must have $A,N \geq 0$. (For this functional form to make sense, $A \leq N$.)

a) Zero Transition Costs

The optimal levels of A and N, assuming no transition costs and both A and N subject to control, are obtained by maximizing equation (1). Those levels are given by:

$$A^* = \frac{30D}{2D+1} \quad , \quad N^* = \frac{30(D+1)}{2D+1} = 30 - A^* .$$

Fixing N at a value N_0, where it would be presumed in the absence of regulation that $N_0 > N^*$, results in an optimal A given by $A_0^* = \frac{D}{D+1} N_0$.

b) Transition Costs

Assume that transition costs can be written in the following way:

$$S(A|A_0^*) = S_0(A-A_0^*)^2 \qquad \text{and} \qquad T(N|N_0) = T_0(N_0-N)^2$$

where S_0 and T_0 are constants.

The optimal levels of A and N, derived by maximizing equation (2), can be written as:

$$A^{**} = \frac{[R(D+1)+T_0]S_0A_0^* + RD(30R+T_0N_0)}{[R(D+1)+S_0][R(D+1)+T_0] - (RD)^2}$$

(3)

$$N^{**} = \frac{(RD)S_0A_0^* + [R(D+1)+S_0](30R+T_0N_0)}{[R(D+1)+S_0][R(D+1)+T_0] - (RD)^2}$$

where $R \equiv \frac{1+r}{r}$. In the table below a discount rate of 10% is used.

	Zero Transition Costs		Transition Costs	
Case 1				
D = 7	$A^* = 14.0$	$N^* = 16.0$	$S_0 = 5.0$	$T_0 = 3.0$
			$A_0^* = 17.5$	$N_0 = 20.0$
			$A^{**} = 14.99$	$N^{**} = 16.97$
Case 2				
D = 7	$A^* = 14.0$	$N^* = 16.0$	$S_0 = 5.0$	$T_0 = 3.0$
Higher starting noise level than Case 1.			$A_0^* = 21.88$	$N_0 = 25.0$
			$A^{**} = 16.23$	$N^{**} = 18.19$
Case 3				
D = 2	$A^* = 12.0$	$N^* = 18.0$	$S_0 = 5.0$	$T_0 = 3.0$
			$A_0^* = 16.67$	$N_0 = 25.0$
			$A^{**} = 13.47$	$N^{**} = 19.48$
Case 4				
D = 2	$A^* = 12.0$	$N^* = 18.0$	$S_0 = 10.0$	$T_0 = 5.0$
Higher transition costs than Case 3.			$A_0^* = 16.67$	$N_0 = 25.0$
			$A^{**} = 14.21$	$N^{**} = 20.20$

The traditional theory of externalities suggests that if producers are charged the marginal costs they impose on the rest of society, an optimal level of externality-generating activity will be determined. We shall now show that this result continues to obtain in the case where there are transition costs away from the initial equilibrium.

First, we must know how much noise costs society at the optimum. It can be seen that the positive or absolute marginal cost of noise to consumers evaluated at the optimal levels of A and N, given by equations (3), can be represented by

$$X^{**} = X(A^{**},N^{**}) = -\frac{\partial H}{\partial N}(A^{**},N^{**}) \ .$$

Assume that this cost is charged to the producers of noise as a per unit effluent charge.

Let us now look to identify all of the costs of noise that will be borne by the producers. These are the costs they will consider in determining their output decisions. The costs fall into three categories: the effluent charges, the per period costs of the noise level, and the transition costs. The expression in equation (4) shows these respectively as the terms $X^{**}N$, $C(N)$, and $T(N|N_0)$. The first two terms must be cumulated over all future time periods. We represent the discounted sum of the noise producers' costs as $P(N)$, where

$$(4) \qquad P(N) = \sum_{t=0}^{\infty} \left\{ \frac{1}{(1+r)^t} [X^{**}N + C(N)] \right\} + T(N|N_0) \ .$$

Evaluating $\partial F/\partial N$ in equation (2) at the optimal levels, A^{**} and N^{**}, yields an expression identical to $-P'(N^{**})$. By definition of the social optimization of $F(A,N)$, $\frac{\partial F}{\partial N}(A^{**},N^{**}) = 0$, implying that $P'(N^{**}) = 0$. (Assume that $P(N)$ has only one extremum in the relavant range of N, which it will for well behaved functions of the type we have specified.) We have shown that from the producers' standpoint, the optimal level of noise associated with minimizing $P(N)$ is $N = N^{**}$. What is significant from a policy standpoint is that this is the same optimal level that was defined in our grand social optimization. An effluent-charge-type scheme works even with transition costs.

An illustration of this result is given by substituting the functions of our numerical example into equation (4), and optimizing. The resulting optimal level of N is given by:

$$N = \frac{1}{R+T_0}[(30R + T_0N_0) - RD(N^{**} - A^{**})] \quad . \tag{5}$$

From equations (3):

$$N^{**} - A^{**} = \frac{(R+S_0)(30R+T_0N_0) - (R+T_0)S_0A_0^*}{[R(D+1)+S_0][R(D+1)+T_0] - (RD)^2} \quad . \tag{6}$$

Substitution of equation (6) into equation (5) yields N = N**.

It is worthwhile to inquire what happens if we set the charge for noise at too high or too low a level at the outset? The answer is nothing at all so long as we continue to reduce the noise level until the computed marginal social cost of noise just equals the incremental cost of proceeding further. So long as we do not stop along the way in such a process, in which case transition costs might mount, this will lead to the N** optimum. Say we start with an effluent charge that is too low. Producers will have the intention to engage in a level of noise reduction that is insufficient. The marginal social cost of noise for their intended level will be above the original effluent charge. The effluent charge will adjust upwards, and the producers will develop more significant levels of intended noise reductions. Through such a process of adjustment of effluent charges, intended noise reductions, and computed marginal social costs of noise, an equilibrium will be reached where the effluent charge just equals the marginal social cost of noise. This occurs when N = N**.

D. IMPLICATIONS AND CONCLUSIONS

1. Alternative Methods of Assessing Willingness-to-Pay

This analysis has concentrated on identifying the appropriate questions to ask when we wish to determine optimal levels of noise reduction, or optimal regulation standards and procedures for noise. Once we know the right questions to ask, we must develop ways to ask them.

There are three basic approaches to the problem of assessing willingness-to-pay for reduced noise levels. The first involves merely asking individuals how much they would be willing to pay for certain levels of noise reductions. The second looks to market transactions to see how much individuals have been implicitly willing to pay in other contexts for noise reduction. The third approach attempts to determine what individuals should be willing to pay for noise reduction. It starts by assessing the harm that the noise produces. It then looks to the costs of remedying part or all of the harm and the implicit costs of various levels of noise-averting activity. Through an examination of the harm that is done, and the costs of correcting or avoiding it, an assessment is made of just how much the noise costs the recipients.

These three procedures have competing advantages. Some will be more appropriately employed in one context; others in others. Since the whole process of determining willingness-to-pay is such a difficult and imprecise matter, it will frequently be worthwhile to conduct such assessments in two or three different forms. Hopefully, there will be a fair degree of agreement among the assessments. If not, we will have at least learned that one or more assessment procedures is subject to significant biases.

Inquiring of individuals directly has the advantage of securing precisely the information that is desired. One can ask any relevant group of individuals, not merely those who happen to be purchasing particular sets of goods. It also allows analysts to pose speculative questions about noise patterns not presently the subject of individuals' experiences.

The disadvantage of this direct approach is that individuals may not give accurate answers about what they really would turn out to be willing to pay. First, they may have substantial difficulty understanding what alternative noise levels represent. They will be expected to cast themselves in the unfamiliar situation of purchasing something that is not normally for sale and which they have never purchased directly. Some of the consequences of their purchase, for example hearing loss or mental disturbance, may be poorly understood by them, and indeed as well by those who pose the questions. Finally, even to the extent that noise recipients understand the questions, they may have the incentive or feel they have the incentive to distort their answers. If they believe the number they provide will be used in policy determination, they could bias their answers to influence the ultimate policy choice. For example, those who are the likely sufferers from a noise externality will give high willingness-to-pay figures if they assume that they will not be charged for noise reductions that might be undertaken in response to those high figures.

There may be other reasons for providing biased answers. One further example suggests the range of possibilities. It is frequently alleged that persons interviewed tend to bias their answers toward what the interviewer expects. Anyone conducting a questionnaire on noise will clearly be interested in that subject. The individual interviewed may give a nice high assessment to show that he too is concerned with the area. Indeed, the very fact of the interview may stimulate his concern in the subject.*

The market-observation procedures would be most attractive if the commodities whose values we wish to assess could be found in the market. Of course they can not. Noise is not bought and sold. Where it is implicitly priced, as say with rental housing, it usually comes along with lots of additional attributes. For example, traffic noise is likely to be accompanied by vehicle-produced air pollution. This would imply that any assessment procedure would have to disentangle these accompaniments.

In this analysis we have suggested that rental differentials may be highly misleading indicators of the value of the differentials in noise disturbance. Unless individuals are identical in their valuation of noise, the rental differentials between high noise disturbance and low noise disturbance locations will not necessarily reflect the valuation of the average individual in either location.** The rent differential certainly does not tell us how much it would be worth to make it quieter in the noisy location, indeed since those individuals are not seeking to move, it would represent an overassessment.

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*Consider the following thought experiment. Ask ten different standardized groups of individuals how much they would pay to achieve a reduction in a specific one among ten different types of environmental degradation. Then scale the sizes of reductions so that the amounts paid were the same for each, i.e., a 10% reduction in air pollution, 35% in noise disturbance, etc. Now ask an eleventh group with the same standardized composition as the other ten how much it would be willing to pay to get one of the ten reductions identified. The particular reduction it will receive will depend upon a random device. The hypothesis that once a concern is singled out it becomes more highly valued would suggest that the answer from this eleventh group will be below that for the ten identified levels of specific types of degradation.

**If these were the only two locations, and if they were identical on all other characteristics, then the rent differential would reflect the valuation of the likely few individuals who were indifferent between the two places. It is quite possible that all of those in the noisy locale would pay far less than the rent differential to get it quiet, whereas those in the quiet location would pay substantially more than the differential to keep it quiet.

One major problem then with market based assessments is that they can not take into account the to be expected difference in the preferences among the human beings who choose to reside in different locations. A second problem is that the noisy and quiet neighborhoods are highly unlikely to be equivalent on a great number of other variables. With a statistical analysis, say a multiple regression, one can hope to correct for these other factors. Realistically, analyses based on such procedures are unlikely to provide the type of unequivocal information on which we might like to base policy. There is likely to be a multitude of variables to correct for, and only a relatively limited sample size.

The third procedure, where we implicitly attempt to determine what individuals should be willing to pay for noise reduction, is perhaps the most difficult to put into practice. There are two major problems. First, we do not really know what the long-term consequences of noise exposure will turn out to be. Second, the disadvantageous impacts of noise are only partly in the monitorable effects. The what is it worth approach runs into great difficulty when it must confront questions such as: In addition to hearing loss and other possible consequences, what is it worth just to avoid the disturbance? In order to address this question, it would seem, we would be driven back to the willingness-to-pay survey approach with which we started.

This third procedure, it is worth mentioning, has frequently been employed when we have attempted to value alternative health interventions. The usual inputs are days of morbidity and probabilities of mortality, which are then weighted by foregone earnings on those days or years. In most instances this estimation procedure would seem to give a lower bound; it leaves out the way people feel about being healthy. The point is made especially strongly when we observed that it implicitly values the morbidity of retired individuals at zero.

What then should be done? This analysis suggests that any approach should be thought of as an uncertain venture. An estimate derived through any one procedure would be open to some of the methodological objectives raised above. A mixed strategy might seem called for. Each of the three procedures should be invoked, and through what might be called a triangulation procedure, it might be determined whether they point toward common values.

It would seem essential then that an effort be made to conduct at least two of three very different types of procedures for assessing willingness-to-pay. If it is thought initially that one of the three approaches is most valuable, then perhaps the bulk of resources should be directed toward it. But it is unlikely that a 100% allocation of funds to a survey approach will prove nearly as informative as 80% to survey, 10% to market assessment, 10% to "how should it be valued." Even if the lesson of the pilot study is that from that point forward all analyses should be conducted by survey, the information that the survey approach was in line with the other two means of generating values would likely prove most reassuring.

2. Conclusion

This analysis highlighted the characteristics of noise disturbance that make it like and unlike other economic goods. A variety of factors were identified that might justify some form of government intervention into the largely nonfunctioning market for noise disturbance. If the government is to intervene on a sensible basis it will have to know how much it is worth to achieve a reduction in noise disturbance. Since the beneficiaries of such a reduction are almost exclusively individuals as opposed to firms, the government must start its policy formulations by determining individuals' willingness-to-pay for a less disturbing level of noise.

The willingness-to-pay determination for noise is much more complicated than it is for most goods, including a variety of other external diseconomies. First, the analyst must take into account the opportunities for noise-averting behavior. Second, he must allow for shifts in equilibrium residential and work patterns in response to changes in noise disturbances at a variety of locations. Third, he must allow for the transition costs to whatever new equilibria will be produced by government intervention. Despite the many complications in the approach, willingness-to-pay is still the key input the government should search for when attempting whether and by what amount to reduce noise disturbance.

Individuals may have grave difficulty providing information of their willingness-to-pay for noise reductions. They are unlikely to be able to predict the consequences of long-term exposure to noise with any precision.

Moreover, they may have a variety of incentives to distort their answers. Assessment procedures that attempt to determine willingness-to-pay by a look to rental differentials between quiet and noisy locations will run into different sets of methodological difficulties. So too, attempts to price out the consequences of noise disturbance are likely to lead to biased and imprecise assessments.

An intelligent assessment of willingness-to-pay will start with an understanding of the array of complicating issues discussed in this paper. It will employ whatever information it can secure by each of a variety of approaches in an attempt to arrive at some reasonable estimates.

Too frequently a policy issue is neglected because the measurement problems make it most difficult to determine with precision just the appropriate level of activity. This may well have been the case with a variety of types of noise disturbance. At this juncture it would surely seem worthwhile to take a preliminary step and attempt to make a determination, however crude, of just what a quieter environment is worth. With that knowledge as the starting point, we can proceed to a more effective policy for controlling disturbance from noise.

CHAPTER III

THE PRICING OF AGGREGATE NOISE DISTURBANCE[1]

by Thomas Holmes

Introduction

The object of this chapter is to determine efficiency criteria for the abatement of aggregate noise disturbance. Aggregate noise disturbance is a physical property of a geographic location and is to be distinguished from the noise emission of a particular one of many local noise emitters. A typical and important instance is the aggregate noise disturbance produced by a congestion of trucks, busses, automobiles and motorcycles in a busy urban area. This example is chosen because traffic noise is one of the most common forms of noise disturbance[2] and because it illustrates most of the economically relevant properties of the aggregate noise disturbance phenomenon.

Aggregate noise disturbance is readily indentified as a form of pollution to which much of the theory developed for other forms of pollution applies. However, each form of pollution has distinguishing properties that must be accomodated by the general theory. At least three distinguishing properties of the aggregate noise disturbance phenomenon are described in Sections A and B of this chapter. This discussion of the properties of noise, along with a discussion of public goods theory in Sections C and D serve to motivate a theorem on the pricing of aggregate noise disturbance in Section E. The theorem and its corollary are proved in Section F. Section G is given over to an interpretation of the theorem.

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[1] I am indebted to Richard Zeckhauser and Harold Payson III for clarification of many points in my interpretation of the mathematical development reported in this chapter, although I bear responsibility for accuracy of the results.

[2] U.S. Environmental Protection Agency, The Economic Impact of Noise (G.P.O., Washington, D.C. 1971) p. 47.

It will be shown that the price theorem is consistent with the general efficiency criterion: the efficient level of aggregate noise abatement is such that the marginal benefit of its provision is just equal to the marginal cost of its production. The price theorem implies that to achieve this condition each noise producer should equate his cost of noise abatement to the product

summed individual willingness-to-pay prices for aggregate noise abatement	x	marginal product of producer's own noise abatement in the production of aggregate noise abatement.

A. Location Specific and Periodic Properties of Noise.

Any measure of aggregate noise disturbance denotes the disturbance at a specific geographic location.[3] In principle, the boundaries of the relevant location can be as narrow as an individual's personal property or as broad as a city or larger administrative unit. It seems practical to choose boundaries such that the level of aggregate noise disturbance, as measured by some generally accepted procedure, is uniform within them. In this chapter, we assume that the relevant locations have been determined by a "Noise Control Board" (NCB) having legal jurisdiction over these locations. For example, we may be concerned with noise disturbance in the vicinity of a central highway passing through town. It would not be unreasonable to suppose that all of the aggregate noise disturbance in this area is caused by passing traffic. Henceforth, reference to aggregate noise disturbance always means aggregate noise disturbance at a specific location, if the location is not otherwise mentioned.

The relationship between time and aggregate noise disturbance distinguishes noise from some other common forms of pollution. Noise disturbance, like other pollutants, varies continuously with time. This relationship can be thought of as a non-negative function. In the very long run, a non-negative, continuous function either increases without bound or it has an upper bound; if it is bounded, then, among various possibilities, either it converges to its bound and becomes a constant function, it exhibits some or all of the features of a periodic function, or it is random. Many forms of pollution are not periodic; for example, particulate pollutants probably increase more or less monotonically and either converge to an upper bound or are explosive. Noise disturbance, however, is both bounded and periodic with a period of one day, at least in the case of traffic noise.[4]

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[3] The implications of noise disturbance as a location specific phenomenon are developed in Chapter 2 of this report.

First, the upper bound; the physics of sound teaches us that in the audible frequency range (16 to 20,000 cps), sound levels in excess of 120-130 decibels cross the threshold of pain; at levels in excess of 165 decibels damage to the ear is likely to occur and the phenomenon cannot properly be described as sound.[5] The periodic variation of noise over time is merely the result of sleeping and waking habits. As the volume of traffic picks up in the early morning hours, so does the level of noise disturbance; the level of noise disturbance remains high during the day and evening, with peaks during rush hours, and declines after midnight as the volume of traffic subsides.[6] Variation between the aggregate noise disturbance of day and night tends to be regular. Thus, the aggregate noise disturbance phenomenon can be completely characterized for the medium-term future by a description of the level of aggregate noise disturbance as a function of time over a typical 24-hour period. Long-term adjustments to the amplitude of the function can be made to represent long-term changes in the factors producing aggregate noise disturbance.

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[4] Long-term.cummulative effects on human health are implied by evidence that long-term exposure to high noise levels causes permanent hearing loss. See U.S. Environmental Protection Agency, Public Health and Welfare Criteria for Noise (GPO, Washington, D.C., July 27, 1973) p. 5-27.

[5] Lyle Yerges, Sound, Noise and Vibration Control (Van Nostrand Reinhold Company, 1969) pp. 10-11; U.S. Environmental Protection Agency, Public Health and Welfare Criteria for Noise (GPO, Washington, D C., July 27, 1973) p. 5-12.

[6] For systematic description of typical noise disturbance patterns, see U.S. Environmental Protection Agency, Community Noise (GPO, Washington, D.C., 1971).

The two properties of location specificity and periodicity greatly simplify the measurement problem. Data on aggregate noise disturbance is required for a given location only for a typical 24-hour period.

B. The Many Sources of Noise and Stochastic Measures.

A third property of aggregate noise disturbance is that it emanates from a large number of different sources, as the example of traffic noise illustrates. In other studies, this situation is referred to as one of many polluters contributing to the same type of pollution, but, to my knowlege, this common phenomenon has not been given the systematic analysis that it deserves. The usual methodology is to assume that pollution emanates from a single source in the basic analysis, and when the existence of many polluters is introduced, it is assumed, as a simplifying measure, that the level of aggregate pollution is equal to the unweighted sum of emissions from each polluter.[7] The additive assumption is not usually applicable to the phenomenon of aggregate noise disturbance. Moreover, the marginal contribution of different noise emitters to the level of aggregate noise disturbance, such as trucks versus automobiles, is almost never equal. This is just to recognize that, today at least, trucks are generally louder and thus more annoying than automobiles.

Logical efficiency criteria for the abatement of aggregate noise disturbance should take these differences into account.

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[7] This assumption is explicit in Joseph J. Seneca and Michael K. Taussig *Environmental Economics,* (Prentice-Hall, Inc., 1974) p. 226; it is implicit in L.E. Ruff, "The Economic Common Sense of Pollution," *Public Interest,* Vol. 19, (Spring, 1970) reprinted in Robert Dorfman, ed., *Economics of the Environment,* (W.W. Norton and Company Inc., 1972) p. 13; it is probably implicit in Robert Dorfman, *Ibid.,* p. xxxviii.

The criteria should provide a set of possibly different standards, based on the relative contribution of different noise emitters, for their joint abatement efforts. If trucks produce more of the aggregate noise disturbance than automobiles, stricter standards ought to be set for trucks than for automobiles. The additive assumption fails to distinguish differences in the relative contribution of different emitters, such as trucks and automobiles, and thus would yield inappropriate standards if applied to a case where the relative contributions are not the same. One of the main results of this chapter is to specify the appropriate criteria for joint abatement efforts.

Unfortunately, nothing can be deduced from economic postulates about the particular form of the relationship between aggregate noise disturbance and different sources of noise; thus, its empirical form should be the subject of high priority study by sound engineers and statisticians. In this chapter, we assume only that the relationship is a function with nice properties, or at least that it can be approximated by such a function. In the equation that follows, the subscript "m" is used to distinguish aggregate noise disturbance r_{m+p} from the privately owned factors of production denoted by $r_i(i=1,2,\ldots,m)$, to be introduced in Section E. Let us define the function R_{m+p}:

(1a) r_{m+p}=aggregate noise disturbance at location p

(1b) r^f_{m+p}=disturbance emanating from noise emitter f at location p

(1c) $r_{m+p}=R_{m+p}(r^1_{m+p},r^2_{m+p},\ldots,r^F_{m+p})$,

where $p=1,2,\ldots, P$ and $r^f_{m+p}\geq 0$.

The function R_{m+p} is the aggregate noise disturbance production function, but rather than using this awkward locution, let us refer to R_{m+p} as the aggregate noise disturbance function, or even more simply, as the disturbance function. The disturbance function is assumed to be differentiable and strictly concave over a relevant region. The concavity assumption means we can scale the function in such a way that the first partial derivatives of the function R_{m+p} are diminishing. Whether or not the concavity assumption agrees with reality should be one of the items of concern for sound engineers. At this juncture, it seems reasonable to suppose that an intensification of the noise disturbance at a single source has a declining marginal impact on the level of aggregate noise disturbance in terms of willingness-to-pay.

If the disturbance function is deterministic, then its arguments, r^f_{m+p}, denote the noise emissions of every noise emitter at location p, and there are F of them. By noise emission is meant the physical sound level that emanates from a noise emitter at location p. The noise emission of a motor vehicle at location p at time t depends on, at least, vehicle type, its mode of operation, state of repair, and physical characteristics of the highway; these factors are either constant or determined by the vehicle owner. However, the chain of causation is interminable; even if it were realistic to suppose it were possible to keep track of what vehicles, in particular, had been on location at any given time, it would still be impractical to proceed with a deterministic methodology due to the complexity of the factors on which noise emission depends.

To render the measurement problem tractable, aggregate noise disturbance r_{m+p} should denote a density function over an appropriate and generally accepted measure of aggregate noise disturbance. The arguments of the disturbance function $(r^1_{m+p}, r^2_{m+p}, \ldots, r^F_{m+p})$ then become random variables denoting the characteristics of the noise disturbance emanating from representative types of noise emitters at location p, such as trucks, busses, automobiles and motorcyles.

The NCB can make its classification as coarse or as fine a partition of the universe of noise emitters as it pleases. For purposes of economic analysis, it is convenient to classify noise emitters by profit maximizing units; that is, by firms. Classification by firms is perhaps not as immediately appealing from the point of view of the measurement problem as partition by major product type, but if we make a simplifying definition, we can retain most of the desireable measurement properties of the coarser partition. We define all firms in our economy to be profit maximizing units which produce a joint range of goods, including motor vehicles. If a firm produces motor vehicles, we restrict its production to one and only one of the product types, namely trucks, busses, automobiles and motorcycles. Thus, for our purposes, a GM truck division and a GM automobile division are defined as distinct firms.

Suppose there are a total of F distinct firms in our economy. Given a classification of noise emitters by firms, the definition of r_{m+p} as a random variable induces a one-to-one relationship between the F firms and the arguments of the disturbance function, $(r^1_{m+p}, r^2_{m+p}, \ldots, r^F_{m+p})$, for every location p=1,2,...,P. In cases where firm f produces no motor vehicles, $r^f_{m+p}=0$. Thus, most entries of the disturbance function are zero.

It seems likely that noise disturbance of vehicles of type f, r^f_{m+p}, would be constructed by an appropriate transformation of (1) a density function over a measure of noise emission (a physical sound level) from vehicles of type f at any location and in any mode of operation, (2) a density function over average time spent on location p by vehicles of type f, (3) the clock time on a 24-hour day (because of the periodicity of aggregate noise disturbance), and (4) a density function over the number of vehicles of type f in operation on location p during a typical day. Factor (1) is determined by decisions of firm f, while factors (2) and (4) are determined by vehicle owners and operators. Factors (2) and (4) also depend on the characteristics of location p. In this chapter, we assume that factor (1), the density function over noise emission, is the only control variable for aggregate noise abatement purposes.

We suspect that the relationship between density functions over a measure of noise emissions from automobiles versus trucks, for example, before noise abatement measures, is similar to the relationship between the two curves shown in Figure (3.1-1). The density function for automobile noise emission puts the weight

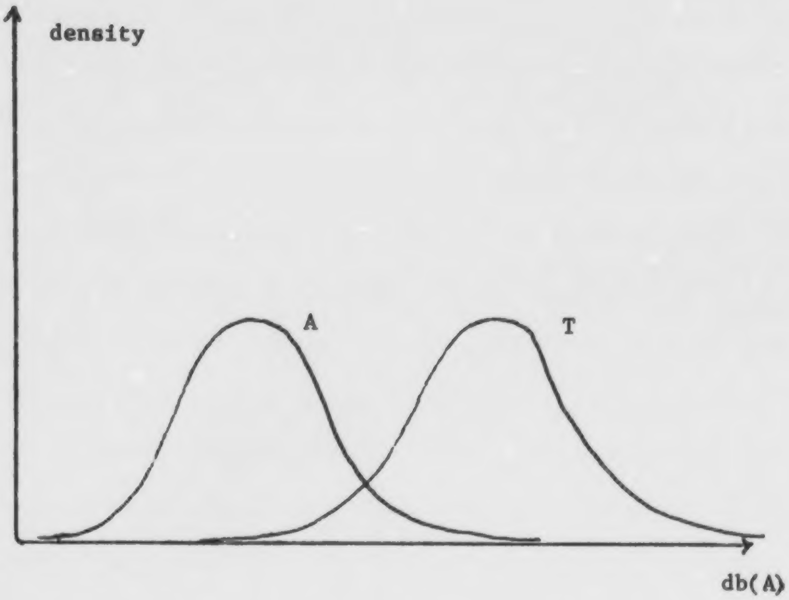

Figure 3.1-1. Before Noise Abatement

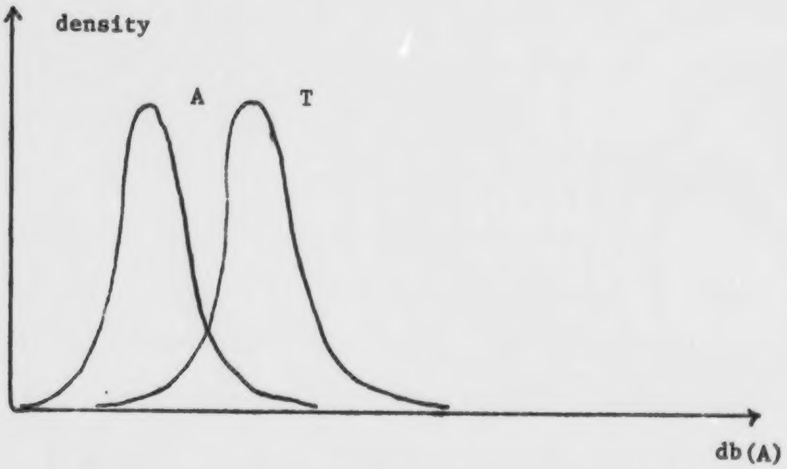

Figure 3.1-2. After Noise Abatement

of noise emissions from automobiles to the left of trucks. After noise abatement, the density functions are closer together and shifted to the left as shown in Figure 3.1-2.

Thus, a third property of aggregate noise disturbance, that it emanates from many uncoordinated noise emitters, strongly suggests that the appropriate measurement technique should be stochastic. Indeed, such measures exist.

One such technique constructs a measure of aggregate noise disturbance from the cumulative density function associated with the density function R_{m+p}. The basic idea is that the psychological experience of noise disturbance correlates directly with the magnitude of the difference between the background noise level and peak noise levels. The background noise level is defined to be the decibel level that is exceeded 90% of the time in one day and the peak noise level is defined to be the decibel level that is exceeded only 10% of the time, these noise levels are given by the 10th and 90th fractiles, respectively, of the cumulative density function associated with R_{m+p}.

As an example, the background noise level in a suburban area might be 35 decibels with peak levels of 75 decibels. This means 90% of the time the noise level exceeds 35 decibels, but 75 decibels is exceeded only 10% of the time. The difference of 40 decibels is used to measure the aggregate noise disturbance.[8]

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[8] For a discussion of such measures, specifically the Traffic Noise Index (TNI), refer to U.S. Environmental Protection Agency, Community Noise, op.cit., pp. 66-79.

Henceforth, noise is always referred to in one of four ways. Aggregate noise disturbance is a random variable referring to the noise characteristics of a given geographic location; it is the object of noise abatement activity. A noise emission refers to (1) the sound emanating from a single noise emitter, or (2) a density function over a measure of noise emission by emitter type. The context shows whether (1) or (2) is intended. Noise disturbance is a random variable denoting the noise characteristics of representative types of noise emitters at a given location.

C. Public Goods, Market Failure and Externalities.

The abatement of aggregate noise disturbance is a public good. Thus, all who frequent the quieted location receive the benefit of an equal magnitude of aggregate noise abatement (although they may have different subjective valuations of the same magnitude) and an addition to the magnitude of aggregate noise abatement by any one individual implies no reduction in the magnitude received by any other. The concept of a public good is familiar and would seem to be the natural formulation when those who jointly benefit are supposed, in principle, to compensate the firms or consumers who jointly produce the benefit, at cost to themselves.[9]

We imagine the NCB levying a tax on those who frequent the locations in its jurisdiction and benefit from aggregate noise abatement. In the case of traffic noise, the NCB, as middleman, supplies the efficient level of aggregate noise abatement to individuals by offering to pay efficient prices to motor vehicle manufacturing firms for the installation of improved noise control systems on new vehicles. The NCB then collects just enough in taxes from the residents and visitors of the area to cover the cost of payments to the vehicle firms.

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[9] For the original statement of the theory of public goods, Paul A Samuelson, "The Pure Theory of Public Expenditure," The Review of Economics and Statistics, Vol. XXXVI, (Nov., 1954) pp. 387-389; and "Diagrammatic Exposition of a Theory of Public Expenditure," Ibid., (Nov. 1955) pp. 350-356.

The concept of a public good is closely associated with the concept of market failure. Part of the "publicness" of the public good is the fact that some form of collective action is usually required to secure an efficient provision of the good because the unaided market mechanism does not bring about this result. It may be instructive to explain why the market fails.

No production occurs if the industry supply price for some commodity X is everywhere above the demand price. It is often the case that the marginal cost of provision of a public good is much greater than any one individual is willing to pay by himself. This situation is pictured in Figure 3.2, which represents an economy consisting of commodity X and two consumers A and B. The supply curve SS is the rising portion of the industry marginal cost curve. DD_A and DD_B are the demand curves of consumers A and B, respectively.

If commodity X is a private good, the absence of production is not the result of market failure; rather, the market functions properly because any production would be inefficient. To contrast this situation to the public good case, we observe that a marginal unit of private good X cannot be jointly consumed by A and B together; if A consumes the marginal unit, B cannot consume it, and vice versa.[10] Therefore, A's demand price for

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[10] Consumption is rival, see Richard A. Musgrave and Peggy B. Musgrave, Public Finance in Theory and Practice, (McGraw Hill, 1973), Chapter 3.

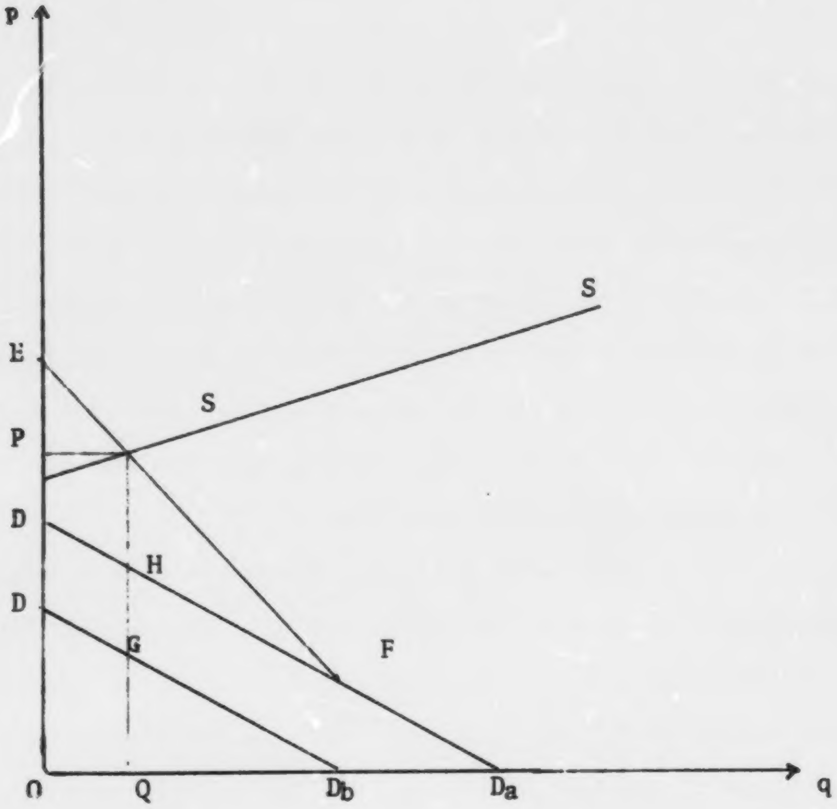

Figure 3.2. Supply and Demand for Commodity X.

B's consumption is zero, and vice versa. There is no community of interest with respect to X, and thus no incentive to pool resources. Since the highest bid price (A's) is less than the cost of producing even the first unit, production of X is zero.

If X is a public good, then both consume a marginal unit equally and an addition to A's consumption implies no subtraction from B's consumption, and vice versa. In this case, A's demand price for B's consumption is the same as his own, and vice versa. The existence of a public good creates a community of interest between A and B and there is a clear incentive to pool resources. They should add respective marginal demand prices for each additional unit of output of X. Together, they may be able to cover the marginal cost of producing a marginal unit which both would then consume equally, whereas singly, neither could cover the marginal cost and consumption would be zero.

Market failure occurs because in the general case of many consumers, A and B would not likely know about each other's demand prices without taking special actions to determine this information. It seems clear that some form of collective action is desirable to bring about the ideal results that would follow from perfect knowledge of everyone's demand prices. The joint (social) demand curve is shown by the curve EFD_A. The equilibrium level of output is OQ and the equilibrium price is OP=QG+QH. The nature of the collective action required is for everyone to inform eachother about their true demand prices and to make an arrangement to inform the producer of their joint bid per unit of output.

The procedure which is usually envisioned for collecting information on demand prices for public goods is a survey in which consumers are asked for their "willingness-to-pay" for a marginal unit of the public good. Thus, demand prices have come to be called willingness-to-pay prices in works on public goods theory.

An externality arises whenever the activities of some firms or consumers impose uncompensated and involuntary costs or benefits on other firms or consumers. The concept of a public good seems to apply to the consumption side of human activity, whereas the concept of externality seems to apply to the production side. Aggregate noise disturbance is an external diseconomy produced by both firms and consumers, but its effects fall almost exclusively on consumers. Current evidence suggests that in most cases noise does not affect the general level of productivity;[11] indeed, it appears that, in some cases loud noise boosts labor productivity. Therefore, we assume that aggregate noise disturbance does not appear in the production functions of firms; however, aggregate noise disturbance is clearly a nuisance to individuals and should appear in their utility functions.

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11. U.S. Environmental Protection Agency, Public Health and Welfare Criteria for Noise, op. cit., page 8-1.

D. Consumers' Rights and Public Factors of Production.

If the NCB defines noise abatement as a public good, as was done in Section C, it implicitly gives property rights to producers in an artificial market set up and administered by the NCB.[12] The NCB requires consumers to pay the producers of noise disturbance for contributions to aggregate noise abatement, and acts as a collection agent for producers.

Alternatively, the NCB could give rights to consumers. It declares a quiet environment as a natural resource to which all consumers have joint ownership rights. Anyone who contributes to aggregate noise disturbance is required to compensate consumers for depletion of this jointly owned resource, and the NCB acts as a collection agent for consumers who own this resource.

A public factor of production is defined as a public natural resource possessed by all consumers in equal amount and to which all consumers have joint ownership rights, such that each individual's possession of the public factor implies no depletion of the amount possessed by any other individual.[13] Conversely, a depletion of a given amount possessed by any one individual implies an equal depletion of the amount possessed by every other individual.

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[12] The terms "producers' rights" and "consumers' rights" as applied in this context are due to David Starrett and Richard Zeckhauser, "Treating External Diseconomies-Markets or Taxes?" in John W. Pratt, Statistical and Mathematical Aspects of Pollution Problems, (Dekker, N.Y., 1974.)

[13] The definition of a public factor of production is adapted from Paul A. Samuelson's definition of a public good, *op. cit.*, (Nov., 1954) p. 387.

The previously introduced notation for aggregate noise disturbance r_{m+p} denotes depletion of the public natural resource defined as a quiet environment at location p. Let the vector $(r^1_{m+p}, r^2_{m+p}, \ldots, r^H_{m+p})$ denote the amounts of aggregate noise disturbance depleted from the stock of quiet at location p owned jointly by all the individuals 1 through H in our economy. From the definition of a public factor, it follows that $r_{m+p}=r^1_{m+p}=r^2_{m+p}=\ldots=r^H_{m+p}$.

A careful study of the relative merits of consumers' rights versus producers' rights is not presented in this chapter. We assert that both cases determine efficient equilibrium levels of aggregate noise abatement, but this does not mean that the two alternatives are equivalent in other respects. For one thing, income distributions are different. If there are no income effects, we conjecture, tentatively, that equilibrium levels of aggregate noise abatement are the same in both cases. The political and administrative problems of implementation of each are obviously quite different.

We assume, in this chapter, that the NCB decides to give rights to consumers. If the disturbance R_{m+p} is deterministic, then magnitude of aggregate noise disturbance r_{m+p} depends on the physical noise emissions of vehicles owned by individuals who can be named by personal or company name. It would be natural for the NCB to levy a direct tax on each noise emitter at a rate dependent on his or her noise emission r^f_{m+p}. In the case of traffic noise, some noise emitters are profit maximizing firms, such as trucking companies, and others are utility maximizing consumers who use privately owned vehicles for their own convenience. To some, a system of direct taxation may seem to have the virtue of fairness, but it makes massive demands on the NCB's information system and requires a complex administrative system for implementation.

If the disturbance function R_{m+p} is stochastic, then, as we have seen, aggregate noise disturbance r_{m+p} depends on the noise disturbance characteristics of different types of motor vehicles classified by firms rather than the noise emissions of particular motor vehicles owned by persons who can be named by name. Since, by assumption, the control variable for aggregate noise abatement purposes is the density function over noise emission by vehicle type, a system of indirect taxation seems appropriate, determined, say, on a state by state basis, and is less complex than the system of direct taxation proposed for the deterministic case. The NCB's for each state present tax bills to every firm f in an amount determined statistically by the magnitude of noise disturbance r^f_{m+p}. If $r^f_{m+p} = 0$, for all p, then firm f's tax bill is zero. This system causes the firms whose products contribute to aggregate noise disturbance to pay for contamination of the quiet environment and provides an incentive for the installation of improved noise emission control systems on new vehicles. Ultimately, the owner of a particular vehicle pays for the additional cost of an improved noise emission control system in the form of a higher purchase price and probably higher operating and service costs.

In the end, the direct and indirect tax systems place the burden of payment on the owners of vehicles, and are equivalent in this respect. It would appear that the system of indirect taxation demands less information and is easier to administer than the system of direct taxation. For this reason, we assume that the NCB elects to implement the system of indirect taxation. A tax on the firm that is ultimately paid for by the consumer is called an excise tax.

E. A Theorem on the Pricing of Aggregate Noise Disturbance.

We now turn to a general equilibrium analysis of the system of motor vehicle noise disturbance excise taxation introduced in Section D. The analysis yields a set of efficient tax rates. The set of tax rates is to be interpreted as a set of efficient unit prices per increment of expected value of noise disturbance, Er^f_{m+p}. We assume that any given firm, referred to as firm f, has significant control over the magnitude of Er^f_{m+p} through its ability to change the density function over the measure of noise emission emanating from vehicles of type f. We assume that the concrete form of this relationship is known to both firm f and the NCB.

Let wf^f_{m+p} denote the price per increment of Er^f_{m+p}. We understand that firm f is free to let Er_{m+p} take on any value that it pleases, provided it pays a daily amount equal to $wf^f_{m+p} \times Er^f_{m+p}$ to the NCB.

A Definition of the Economy

Let the economy consist of F firms, H individuals, n private consumption goods, m private primary factors, and aggregate noise disturbance at P different locations.

We respecify the disturbance function R_{m+p} as a density function over the random variable r_{m+p} such that:

(2a) r_{m+p} = aggregate noise disturbance at location p;

(2b) Er^{f}_{m+p} = the expected value of noise disturbance of the type of vehicle produced by firm f;

(2c) $r_{m+p} = R_{m+p}(Er^{1}_{m+p}, Er^{2}_{m+p}, \ldots, Er^{F}_{m+p})$

where $p=1,\ldots,P$,

$$r^{f}_{m+p} \geq 0, \quad \text{and} \quad \frac{\partial R_{m+p}}{\partial r^{f}_{m+p}} > 0.$$

The density function (2c) is assumed to be a stochastic, differentiable production function for r_{m+p}. In order to preserve our Section B assumption of diminishing marginal returns, we assume that the expected value function Er^{f}_{m+p} is strictly concave over a relevant region.

In conformity with notational conventions and general equilibrium methodology of standard economic textbooks,[14] let the following vectors denote the physical elements of the economy:

	Vector	Definition of Each Component
(3a)	$c^h = (c^h_1, c^h_2, \ldots, c^h_n)$	private good j consumed by individual h, $j=1,2,\ldots,n$;
(3b)	$r^h_o = (r^h_{o1}, r^h_{o2}, \ldots, r^h_{om})$	initial stock of private factor i owned by individual h, $i=1,2,\ldots,m$;
(3c)	$r^h = (r^h_1, r^h_2, \ldots, r^h_m)$	private factor i supplied by individual h, $i=1,2,\ldots,m$;

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[14] James M. Henderson and Richard E Quandt, Microeconomic Theory, (McGraw Hill, Inc., 1971) chapter 7; Michael D. Intriligator, Mathematical Optimization and Economic Theory, (Prentice - Hall Inc., 1971) chapters 8 and 9.

Vector	Component
(3d) $r_p = (r_{m+1}, r_{m+2}, \ldots, r_{m+P})$	public factor p (aggregate noise disturbance at location p) supplied by H individuals equally, p=1,2,...,P;
(3e) $c^f = (c^f_1, c^f_2, \ldots, c^f_n)$	quantity of private good j sold by firm f, j=1,2,...,n;
(3f) $r^f = (r^f_1, r^f_2, \ldots, r^f_m)$	quantity of private factor i purchased by firm f, i=1,2,...,m;
(3g) $Er^f_p = (Er^f_{m+1}, Er^f_{m+2}, \ldots, Er^f_{m+P})$	quantity of public factor p (expected value of noise disturbance at location p) purchased by firm f, p=1,2,...,P.

With the understanding that, henceforth, components of Er^f_p are expected values, we suppress the operators and write the vector r^f_p

(3g′) $r^f_p = (r^f_{m+1}, r^f_{m+2}, \ldots, r^f_{m+P})$.

Likewise, we suppress the operators in the disturbance function r_{m+p} and write

(2c′) $r_{m+p} = R_{m+p}(r^1_{m+p}, r^2_{m+2}, \ldots, r^F_{m+p})$.

The relevant price vectors are given by:

Vector	Component
(4a) $p = (p_1, p_2, \ldots, p_n)$	price of private good j, j=1,2,...,n;

Vector	Component
(4b) $w = (w_1, w_2, \ldots, w_m)$	price of private factor i, 1=1,2,...,m;
(4c) $wh_p = (wh_p^1, wh_p^2, \ldots, wh_p^H)$	selling price of every individual h for location p aggregate noise disturbance r_{m+p}(location fixed, p=1,2,...,P) h=1,2,...,H;
(4d) $wh_p^h = (wh_1^h, wh_2^h, \ldots, wh_p^h)$	selling price of individual h for location p aggregate noise disturbance r_{m+p} (individual fixed h=1,2,...,H) p=1,2,...,P
(4e) $wf_p = (wf_p^1, wf_p^2, \ldots, wf_p^F)$	demand price of every firm f for location p own noise disturbance r_{m+p}^f (location fixed, p=1,2,...,P,) f=1,2,...,F;
(4f) $wf_p^f = (wf_1^f, wf_2^f, \ldots, wf_p^f)$	demand price of firm f for location p own noise disturbance r_{m+p}^f(firm fixed, f=1,2,...,F,) p=1,2,...,P.

The profits of all firms are summarized by the vector

$$(5) \quad \pi = (\pi_1, \pi_2, \ldots, \pi_F)$$

We assume that individuals own shares in firms and that all profit accruing to the firms is divided between the owners in proportional shares. Let s_f^h be the share of firm f owned by individual h. Then ownership of firms by individual h is given by

$$(6) \quad s_h = (s_1^h, s_2^h, \ldots, s_F^h)$$

where $\sum_{h=1}^{H} s_f^h = 1$.

We assume that the economy is competitive and that individuals maximize utility functions U_h

$$(7)\quad U_h = U_h(c^h, r_o^h - r^h, -r_p), \quad h=1,2,\ldots,H$$

subject to a real valued budget constraint [15]

$$(8)\quad w.r^h + wh_p^h.r_p + s^h.\pi = p.c^h, \quad h=1,2,\ldots,H.$$

We also assume that the total income recieved by individual h from the sale of factors and share of profits of firms is spent on goods and services.

Firms maximize real valued profit functions,

$$(9)\quad \pi_f = p.c^f - w.r^f - wf_p^f . r_p^f \qquad f=1,2,\ldots,F$$

subject to a production function

$$(10)\quad F_f\,(c^f; r^f; r_p^f) = 0 \qquad f=1,2,\ldots,F.$$

In addition, we require that private markets are cleared,

$$(11)\quad \sum_{h=1}^{H} c_j^h - \sum_{f=1}^{F} c_j^f = 0 \qquad j=1,2,\ldots,n$$

$$(12)\quad \sum_{h=1}^{H} r_i^h - \sum_{f=1}^{F} r_i^f = 0 \qquad i=1,2,\ldots,m;$$

and recall that

$$(2c')\quad r_{m+p} - R_{m+p}(r_{m+p}^1, r_{m+p}^2, \ldots, r_{m+p}^F) = 0, \quad p=1,2,\ldots,P$$

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[15] Each term in equations (8) and (9) is the usual real valued, inner product of vectors; for example,

$$w.r^h = \sum_{i=1}^{n} w_i r_i^h, \quad \text{and} \quad wh_p^h.r_p = \sum_{p=1}^{P} wh_p^h\, r_{m+p}$$

Equation (7) is the utility function U_h of individual h and equation (10) is the firm's production function in implicit form. Both (7) and (10) are assumed to be differentiable over a relevant region; equation (7) has all positive first order partial derivatives, the production function (10) has postive first order partials for all outputs and negative first order partials for all inputs; (7) and (10) possess negative definite Hessian matricies of second order partial derivatives. The negative definite condition on (7) implies that the set of all commodity combinations which yield a utility level equal to or greater than some fixed indifference hypersurface U_{ho} form a closed, strictly convex point set.[16] The negative definite condition on (10) implies that the input-output combinations defined by $F_f(c^f;r^f;r_p^f) \geq 0$ form a closed, strictly convex point set.[17] These stringent assumptions of strict convexity everywhere are made for analytical purposes, in order to guarantee the existence of a unique solution to the general equilibrium problem.[18]

In particular, the assumptions of strict convexity imply that indifference curves for consumption goods in two dimensions are convex for every individual h. For every firm f, all one-

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16. James M. Henderson and Richard E. Quandt, Ibid., p.39.

17. Ibid., p. 97.

18. Ibid., p. 189

output production functions obtained by fixing the values of the other (n-1) outputs are strictly concave, and all one-input production functions obtained by fixing the values of the other (m+P - 1) inputs will be strictly convex.[19]

The initial stock associated with the public factor r_p is included in the utility function U_h as zero. A zero entry denotes an absence of aggregate noise disturbance. We take zero aggregate noise disturbance, or at least a noise level that is hardly ever, if at all, annoying, as a benchmark corresponding to the vector r_o^h.

Statement of the Price Theorem

A basic theorem in general equilibrium analysis is that for a competitive economy in which there are n private goods and m private factors, and in which individual utility and production functions have properties implying strict convexity everywhere, as assumed in this chapter, then there exists a unique set of prices and wages such that (loosely speaking) the value of each private good in consumption is equal to or greater than its opportunity costs of provision in alternative uses of resources.[20] We assume that a pure, competitive equilibrium exists in the private goods and factor markets of our economy. This means that if there are no public factors to consider, then price vectors p and w, given by definitions (4a) and (4b), exist and are unique.

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[19] Ibid,. p. 97

[20] Discussions of the general equilibrium problem may be found in James M. Henderson and Richard E. Quandt, Ibid., pp. 189-190; Michael D. Intrilegator, op. cit., pp 238-241; Gerard Debreu, Theory of Value, (Wiley, 1959).

Therefore, all that we must do to solve the general equilibrium problem, given the existence of a vector of public factors r_p in an otherwise purely competitive economy, is to exhibit a set of prices that are consistent with equations and definitions (2) through (12), less (4), and show that these prices exist and are unique. In particular, we want the prices of aggregate noise disturbance to be consistent with utility mazimization by individuals and profit maximization by firms. The prices we want to exhibit are those which the NCB should post in order to guarantee an equilibrium.

If NCB does not exist, or does nothing, an equilibrium exists, nevertheless, in private markets. However, an equilibrium that does not include positive prices for the public factor of noise disturbance is not efficient, as we shall demonstrate.

A necessary condition for an economic optimium is that the economy is in a state of Pareto efficiency.[21] A Pareto efficient state is an economic situation in which no feasible reallocation of physical resources would increase the level of utility of any individual without lowering the level of utility of at least one other individual. An economic optimium is necessarily Pareto efficient since otherwise some individual can be made better off without making any others worse off, a redistribution which is clearly an improvement. Consequently, we want the selling prices given in (4c) and the demand prices given in (4e) to be consistent with a Pareto efficient state.

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[21] Michael D. Intriligator, op. cit., pp. 258-259.

Selling prices for a public factor correspond to willingness-to-pay prices in the analysis of public goods. The selling prices monetize the marginal costs imposed on individuals by an increment to aggregate noise disturbance r_{m+p}. To allow for noise averting behavior, we assume that selling prices are those demanded by individuals after optimal noise averting actions have been taken.[22] We assume that the NCB has perfect knowlege of the relevant selling prices, obtained, say by means of a survey. Selling prices are given by the vector wh_p in definition (4c). The components of wh_p denote the marginal costs to individuals h=1,2, ...,H for an increment to r_{m+p}. In other words, the component wh_p^h could be interpreted as a bribe denoting the amount of money required by individual h in order to be indifferent between no increment to r_{m+p} and no bribe, and an increment to r_{m+p} with a bribe and the opportunity to engage in averting activities. The set of all such amounts for all possible levels of r_{m+p} forms the supply function of individual h for r_{m+p}, as shown in Figure 3.3.

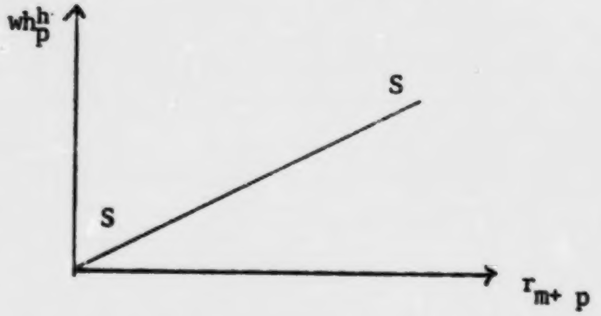

Figure 3.3 Supply Function of Individual h for Aggregate Noise Disturbance r_{m+p}.

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[22] The Efficient Outcome with Noise Averting Activities is discussed in Chapter 2 of this report.

We have assumed that $\partial U_n/\partial(-r_{m+p}) \geq 0$ for all $r_{m+p} \geq 0$. Hence, $\partial U_n/\partial r_{m+p} \geq 0$, and it follows that $dwh_p^h/dr_{m+p} \geq 0$ (if this derivative exists). This condition is consistent with the rising slope of the SS curve in Figure 3.3.[23] We assume that the NCB obtains perfect information on the selling prices wh_p^h of every individual for each possible level of the components of r_p.

We now collect assumptions and state the following

Price Theorem Given selling prices $wh_p=(wh_p^1, wh_p^2, \ldots, wh_p^H)$ of individuals for aggregate noise disturbance r_{m+p} at location p, there exists a set of demand prices of firms for input rights to noise disturbance r_{m+p}^f, denoted by the vector $wf_p=(wf_p^1, wf_p^2, \ldots, wf_p^F)$.

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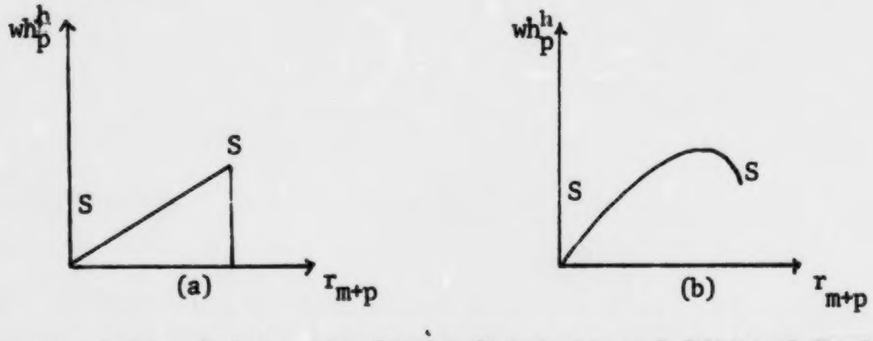
[23] It must be noted that nonconvexities probably exist. The requirement $\partial U_n/\partial r_{m+p}$ 0 means increasing disutility obtains for all $r_{m+p} \geq 0$. However, for r_{m+p} greater than some value, it is likely that $\partial U_n/\partial r_{m+p} \geq 0$ for two reasons: (1) the individual can leave location p if it gets too loud for him, or (2) he may get saturated and not care about increasing noise disturbance above a certain level. In case (1), Figure 3.3 would look like (a), while case (2) could have the shape shown in (b).



On non-convexities, see David Starrett and Richard Zeckhauser, *op. cit.*, pp. 72-75 and p. 80; and William J. Baumol, "On Taxation and the Control of Externalities", *American Economic Review*, Vol. 62, (June, 1972), p. 317.

The components of wh_p and wf_p are related by the formula

$$(13) \quad wf_p^f = \sum_{h=1}^{H} wh_p^h \frac{\partial R_{m+p}}{\partial r_{m+p}^f} \qquad \begin{array}{l} f=1,2,\ldots,F \\ p=1,2,\ldots,P. \end{array}$$

Equation (13) defines wf_p^h for every f and every p. The vector wf_p is the only set of demand prices consistent with the requirements (a) firms maximize profits, (b) individuals maximize utility, and (c) the allocation of resources is Pareto efficient.

Corollary Resource allocation in competive markets is Pareto efficient only if equation (13) is satisfied.

Equation (13) requires that the per unit price paid by firm f for own noise disturbance r_{m+p}^f at location p is equal to

summed individual supply prices for aggregate noise disturbance r_{m+p}	x	marginal product of firm's own noise disturbance r_{m+p}^f in the production of aggregate noise disturbance.

F. Proofs of the Price Theorem and its Corollary

A proof of the price theorem proceeds from the assumption that requirements (a), (b) and (c) hold, along with equations and definitions (2) through (12). First, a Pareto efficiency criterion for public factor markets covering the allocation of aggregate noise disturbance r_{m+p} is deduced. Second, we exhibit necessary first-order conditions for maximum utility and maximum profit, then equation (13) follows easily from the first-order conditions and the Pareto efficiency criterion. Third, the corollary is proved.

A Pareto Efficiency Criterion

From the definition of Pareto efficiency given in Section E, it follows that a necessary and sufficient condition for a Pareto efficient economic state is that an arbitrary individual h maximizes utility subject to the (F + P + n + m) constraints given by (10), (2c′) (11), and (12) and the (H-1) fixed utility levels U_{qo}, $q=1,2,\ldots,H$, $q \neq h$. To deduce necessary conditions for Pareto efficiency, it is sufficient to maximize the utility level of an arbitrary individual, say h=1, subject to the above constraints. Form the Lagrangian Z:

$$(14)\quad Z=U_1 + \sum_{h=2}^{H} \lambda h(U_h - U_{ho}) + \sum_{f=1}^{F} \theta_f F_f + \sum_{j=1}^{n} \alpha_j\left(\sum_{f=1}^{F} c_j^f - \sum_{h=1}^{H} c_j^h\right) + \sum_{i=1}^{m} \beta_i\left(\sum_{h=1}^{H} r_i^h - \sum_{f=1}^{F} r_i^f\right) + \sum_{p=1}^{P} \delta_p(r_{m+p} - R_{m+p}).$$

The relevant first order necessary conditions for a maximum are

$$(15a)\quad \frac{\partial Z}{\partial r_i^1} = -\frac{\partial U_1}{\partial r_i^1} + \beta_i = 0 \quad i=1,2,\ldots,m$$

$$(15b)\quad \frac{\partial Z}{\partial r_i^h} = -\lambda_h \frac{\partial U_h}{\partial r_i^h} + \beta_i = 0 \quad \begin{array}{l} h=2,3,\ldots,H \\ i=1,2,\ldots,m \end{array}$$

$$(15c)\quad \frac{\partial Z}{\partial r_i^f} = \theta_f \frac{\partial F_f}{\partial r_i^f} - \beta_i = 0 \quad \begin{array}{l} f=1,2,\ldots,F \\ i=1,2,\ldots,m \end{array}$$

$$(15d)\quad \frac{\partial Z}{\partial r_{m+p}} = -\frac{\partial U_1}{r_{m+p}} - \sum_{h=2}^{H} \lambda_h \frac{\partial U_h}{\partial r_{m+p}} + \delta_p = 0 \quad p=1,2,\ldots,P$$

$$(15e)\quad \frac{\partial Z}{\partial r_{m+p}^f} = \theta_f \frac{\partial F_f}{\partial r_{m+p}^f} - \delta_p \frac{\partial R_{m+p}}{\partial r_{m+p}^f} = 0 \quad \begin{array}{l} f=1,2,\ldots,F \\ p=1,2,\ldots,P \end{array}$$

Assuming that other first order and the second order conditions for a maximum are satisfied, we may proceed to derive a necessary Pareto efficiency criterion for public markets.

We show that, in public factor markets

$$(16)\quad \sum_{h=1}^{H} \frac{\partial U_h/\partial r_{m+p}}{\partial U_h/\partial r_i^h} = \frac{\partial F_1/\partial r_{m+p}^1}{\partial F_1/\partial r_i^1} \; \frac{1}{\partial R_{m+p}/\partial r_{m+p}^1} = \frac{\partial F_2/\partial r_{m+p}^2}{\partial F_2/\partial r_i^2} \; \frac{1}{\partial R_{m+p}/\partial r_{m+p}^2}$$

$$= \ldots = \frac{\partial F_F/\partial r_{m+p}^r}{\partial F_F/\partial r_i^F} \; \frac{1}{\partial R_{m+p}/\partial r_{m+p}^F} \quad \begin{array}{l} p=1,2,\ldots,P \text{ and} \\ i=1,2,\ldots,m. \end{array}$$

Condition (16) asserts that the sum, over every individual, of the marginal rates of substitution of the p_{th} aggregate noise disturbance

r_{m+p} for the i_{th} private factor r_i^h is equal to the weighted rate of technical substitution of every firm of own noise disturbance r_{m+p}^f for the firm's use of the i_{th} private factor r_i^f, where the weight is, in each case, the reciprocal of the marginal product of r_{m+p}^f in the production of r_{m+p}. Since (16) is a necessary condition for Pareto efficiency, requirement (c) of the price theorem holds only if (16) holds.

To show (16), rewrite (15d) as

$$(17a) \quad \frac{\partial U_1}{\partial r_{m+p}} + \sum_{h=2}^{H} \lambda_h \frac{\partial U_h}{\partial r_{m+p}} = \delta_p .$$

Equation (15e) implies

$$(17b) \quad \delta_p = \theta_f \frac{\partial F_f / \partial r_{m+p}^f}{\partial R_{m+p} / \partial r_{m+p}^f} .$$

Thus, substituting (17b) in (17a) yields

$$(17c) \quad \frac{\partial U_1}{\partial r_{m+p}} + \sum_{h=2}^{H} h \frac{\partial U_h}{\partial r_{m+p}} = \theta_f \frac{\partial F_f / \partial r_{m+p}^f}{\partial R_{m+p} / \partial r_{m+p}^f}$$

Now from (15b) and (15c),

$$(17d) \quad \lambda_h = \frac{\beta_i}{\partial U_h / \partial r_i^h} \quad \text{and}$$

$$(17e) \quad \theta_f = \frac{\beta i}{\partial F_f / \partial r_i^f}$$

Substitution of (17d) and (17e) in (17c) yields

$$(17f) \quad \frac{\partial U_1}{\partial r_{m+p}} + \sum_{h=2}^{H} \beta_i \frac{\partial U_h / \partial r_{m+p}}{\partial U_h / \partial r_i^h} = \beta_i \frac{\partial F_f / \partial r_{m+p}^f}{\partial F_f / \partial r_i^f} \quad \frac{1}{\partial R_{m+p} / \partial r_{m+p}^f} ,$$

but (15a) shows

$$(17g) \quad \beta_i = \frac{\partial U_1}{r_i^1} \quad .$$

Divide both sides of (17f) by β_i, and substitute $\partial U_1/\partial r_i^1$ for β_i to obtain

$$(17h) \quad \sum_{h=1}^{H} \frac{\partial U_h/\partial r_{m+p}}{\partial U_h/\partial r_i^h} = \frac{\partial F_f/\partial r_{m+p}^f}{\partial F_f/\partial r_i^f} \cdot \frac{1}{\partial R_{m+p}/\partial r_{m+p}^f} \quad .$$

Now (17h) holds for every f=1,2,...,F. The left hand sides of all such equations, for a fixed i, are equal. Thus, by transitivity, the right hand sides are all equal. This completes a proof of equation (16).

A Proof of the Existence and Uniqueness of wf_p^f.

We now assume that requirements (a), (b), and (c) hold; profit maximization conditions are given by equations (9) and (10). We form the Lagrangian

$$(18) \quad Q = p.c^f - w.r^f - wf_p^f\,.r_p^f + v_f F_f \quad f=1,2,\dots,F.$$

Relevant first-order necessary conditions are given by

$$(19a) \quad \frac{\partial Q}{\partial r_i^f} = -w_i + v_f \frac{\partial F_f}{\partial r_i^f} = 0 \quad i=1,2,\dots,m \text{ and } f=1,2,\dots,F;$$

$$(19b) \quad \frac{\partial Q}{\partial r_{m+p}^f} = -wf_p^f + v_f \frac{\partial F_f}{\partial r_{m+p}^f} = 0 \quad p=1,2,\dots,P \text{ and } f=1,2,\dots,F.$$

Utility maximizing conditions are given by equations (7) and (8). We form the Lagrangian

$$(20)\quad M=U_h + y_h(w.r^h + wh^h_p.r_p + s^h.\Pi - p.c^h) \quad h=1,2,\ldots,H.$$

relevant first-order necessary conditions are

$$(21a)\quad \frac{\partial M}{\partial r^h_i} = -\frac{\partial U_h}{\partial r^h_i} + y_h\, w_i = 0 \quad i=1,2,\ldots,m \text{ and } h=1,2,\ldots,H;$$

$$(21b)\quad \frac{\partial M}{\partial r_{m+p}} = -\frac{\partial U_h}{\partial r_{m+p}} + y_h\, wh^h_p = 0 \quad p=1,2,\ldots,P \text{ and } h=1,2,\ldots,H.$$

We assume that other first-order and the second order conditions for a maximum are satisfied.

Inspection of the profit functions (9) and budget constraints (8) shows that multiplication of both sides of (9) and (8) by a scalar does not change the equilibrium solution. Thus, all supply and demand functions are homogeneous of degree zero in all prices, and we are free to choose a numeraire. Define the i_{th} private factor as numeriare; we set $w_i=1$. From (19a) and (19b) we obtain by division,

$$(22)\quad \frac{\partial F_f/\partial r^f_{m+p}}{\partial F_f/\partial r^f_i} = \frac{wf^f_p}{w_i} = wf^f_p \qquad \begin{array}{l} p=1,2,\ldots,P \\ f=1,2,\ldots,F \end{array}$$

and from (21a) and 21b), we obtain

$$(23)\quad \frac{\partial U_h/\partial r_{m+p}}{\partial U_h/\partial r^h_i} = \frac{wh^h_p}{w_i} = wh^h_p \qquad \begin{array}{l} p=1,2,\ldots,P \\ h=1,2,\ldots,H. \end{array}$$

Now requirement (c) implies equation (16) which states

$$(16) \quad \sum_{h=1}^{H} \frac{\partial U_h/\partial r_{m+p}}{\partial R_{m+p}/\partial r_i^h} = \frac{\partial F_f/\partial r_{m+p}^f}{\partial F_f/\partial r_i^f} \frac{1}{\partial R_{m+p}/\partial r_{m+p}^f} \quad \text{for all } \begin{array}{l} f=1,2,\ldots,F; \\ p=1,2,\ldots,P; \\ i=1,2,\ldots,m. \end{array}$$

From (22) substitute wf_p^f on the right-hand side of (16) and cross multiply by $\partial R_{m+p}/\partial r_{m+p}^f$ to obtain

$$(24) \quad \sum_{h=1}^{H} \frac{\partial U_h/\partial r_{m+p}}{\partial U_h/\partial r_i^h} \frac{\partial R_{m+p}}{\partial r_{m+p}^f} = wf_p^f.$$

If (23) is multiplied on both sides by $\partial R_{m+p}/\partial r_{m+p}^f$, we get

$$(25) \quad \frac{\partial U_h/\partial r_{m+p}}{\partial U_h/\partial r_i^h} \frac{\partial R_{m+p}}{\partial r_{m+p}^f} = wh_p^h \frac{\partial R_{m+p}}{\partial r_{m+p}^f} \quad \text{for } h=1,2,\ldots,H.$$

For each h=1,2,...,H, substitute the right hand side of (25) for the h_{th} term of the sum on the left hand side of (24). This yields

$$(13) \quad \sum_{h=1}^{H} \left(wh_p^h \frac{\partial R_{m+p}}{\partial r_{m+p}^f}\right) = wf_p^f \quad \begin{array}{l} f=1,2,\ldots,F \\ p=1,2,\ldots,P, \end{array}$$

as desired. This proves that equation (13) holds if (a) firms maximize profits, (b) individuals maximize utility, and (c) the allocation of resources is Pareto efficient. By assumption the vector $wh_p=(wh_p^1, wh_p^2, \ldots, wh_p^H)$ exists; hence, the existence and uniqueness of each wf_p^f is guaranteed by equation (13).

A Proof of the Corollary.

Assume that resources are allocated in competitive markets, and assume that all public and private markets are in equilibrium. This equilibrium is a possible candidate for Pareto efficiency, since it is well known that a competitive equilibrium in private markets satisfies some necessary conditions for Pareto efficiency. Now suppose that the equilibrium is Pareto efficient. We show that a contradiction results if we also suppose that equation (13) is not satisfied. The inconsistency of these two suppositions proves that a competitive equilibrium is Pareto efficient only if equation (13) is satisfied.

The price theorem states that requirements (a), (b) and (c) together imply equation (13); the contrapositive of this implication requires that if equation (13) is not satisfied, then at least one of the three requirements is not satisfied. But the analysis of pure competition shows that failure of either requirement (a) or (b) is sufficient to guarantee failure of requirement (c). This proves that equation (13) is a necessary condition for Pareto efficiency.

We observe that equation (13) is not sufficient for Pareto efficiency; for example, if private markets are not in a state of competitive equilibrium, then the economy is not in a Pareto efficient state. Either both partial equilibriums in private and public markets are Pareto efficient, or neither is Pareto efficient.

If an economic state is Pareto efficient, we say that the economy is efficient. We note that we did not have to assume the existence of competitive markets in order to prove the price theorem.

G. Interpretation of the Price Theorem.

Equality of Cost and Benefit of r_{m+p}.

An efficient economic state implies that the marginal cost and benefit of aggregate noise disturbance are equal. Consider equation (16),

$$(16) \quad \sum_{h=1}^{H} \frac{\partial U_h / \partial r_{m+p}}{\partial U_h / \partial r_i^h} = \frac{\partial F_f / \partial r_{m+p}^f}{\partial F_f / \partial r_i^f} \; \frac{1}{\partial R_{m+p} / \partial r_{m+p}^f} \; .$$

On the left hand side, we have the marginal cost of an increment to aggregate noise disturbance r_{m+p} (MC_p). That is, using (23),

$$(26) \quad \sum_{h=1}^{H} \frac{\partial U_h / r_{m+p}}{\partial U_h / \partial r_i^h} = \sum_{h=1}^{H} wh_p^h = MC_p .$$

The vector $wh_p = (wh_p^1, wh_p^2, \ldots, wh_p^H)$ denotes the selling prices of individuals for an increment to r_{m+p}. The sum of such selling prices is the marginal cost to society for an increment of aggregate noise abatement r_{m+p}. We now show that the right side of (16) denotes the marginal benefit to society for increments to r_{m+p}. From first order conditions for competitive profit maximization, it is easy to deduce the condition

$$(26) \quad \frac{\partial F_f / \partial r_{m+p}^f}{\partial F_f / \partial c_j^f} = \frac{\partial c_j}{\partial r_{m+p}^f} = - \frac{wf_p^f}{p_j}$$

or taking the absolute value of the two right-most expressions,

$$(27) \quad \frac{\partial c_j}{\partial r_{m+p}^f} = MPf_p^j = \frac{wf_p^f}{p_j}$$

The magnitude of the partial derivative $\partial c_j/\partial r^f_{m+p}$ if it exists is interpreted as the marginal product of r^f_{m+p} in the production of an arbitrary private good, c_j. Thus

$$(28) \quad wf^f_p = p_j \, MPf^j_p.$$

Equation (28) shows that firm f's profit maximizing demand price per unit of r^f_{m+p} is equal to the value of the marginal product of his own noise disturbance r^f_{m+p} in the production of c_j. To obtain the value of the marginal product of aggregate noise disturbance r_{m+p} in the production of c_j, we have to distribute $p_j \, MPf^j_p$ over the increment to r_{m+p} that results from a unit increment to r^f_{m+p}. This is done by dividing $p_j \, MPf^j_p$ by $\partial R^f_{m+p}/\partial r^f_{m+p}$; that is

$$(29) \quad \frac{wf^f_p}{\partial R_{m+p}/\partial r^f_{m+p}} = \frac{p_j \, MPf^j_p}{\partial R_{m+p}/\partial r^f_{m+p}} = MB^f_p.$$

The middle expression of equation (29) is the marginal benifit of an increment of aggregate noise disturbance r_{m+p} produced by firm f (MB^f_p). Using equations (22) and (29), we can write

$$(30) \quad \frac{\partial F_f/\partial r^f_{m+p}}{\partial F_f/\partial r^f_1} \; \frac{1}{\partial R_{m+p}/\partial r^f_{m+p}} = \frac{wf^f_p}{\partial R_{m+p}/\partial r^f_{m+p}} = MB^f_p.$$

Equation (30) is valid for all firms f=1,2,...,F. Equations (16), (26), and (30) demonstrate that in a competitive equilibrium, the marginal cost of an increment of r_{m+p}, denoted MC_p, just equals the marginal benefit of its use in production by an arbitrary firm, denoted by MB_p^f; thus, we have $MC_p=MB_p^f$ for all $f=1,2,\ldots,F$. By transitivity, $MB_p^1=MB_p^2=\ldots=MP_p^F$. This shows that the marginal cost of aggregate noise disturbance everywhere just equals the marginal benefit of its use in production by firms. This result is the usual result obtained in the theory of public goods.[24]

Price Differentiation and Own Noise Disturbance

A consequence of the price theorem is that efficient unit prices paid by different firms to the NCB for rights to use own noise disturbance are equal in a competitive equilibrium only if different firms produce the same aggregate noise disturbance. That is

$$\text{(31a)} \quad wf_p^f = wf_p^g \text{ if and only if}$$

$$\text{(31b)} \quad \frac{\partial R_{m+p}}{\partial r_{m+p}^f} = \frac{\partial R_{m+p}}{\partial r_{m+p}^g}$$

where $g \neq f$, $g,f=1,2,\ldots,F$.

Equality (31b) holds in special cases. An example of a special case where equality (31b) holds is when the disturbance function R_{m+p} is an unweighted sum of its arguments

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[24] For example, "the broad productivity criterion requires that emissions be controlled in such a way that the marginal cost of further reductions be the same for all sources of pollution". Robert Dorfman, op.cit., p xxxvii. Also "Once cost and benefit functions are known,the PCB [Pollution Control Board] should choose a level of abatement that maximizes net gain. This occurs where the marginal cost of further abatement just equals the marginal benefit". L.E. Ruff, reprinted in Ibid., p 11.

$$(32)\quad r_{m+p}=R_{m+p}(r^1_{m+p},r^2_{m+p},\ldots,r^F_{m+p}) = r^1_{m+p}+ r^2_{m+p}+ \ldots + r^F_{m+p}.$$

In Section B, we saw why this function which, for the sake of simplicity, is often assumed in the many-polluter case, does not usually characterize the phenomenon of aggregate noise disturbance.

The possibility of unequal unit prices for noise disturbance is perhaps counter to expectations because the familiar analysis of pure competition shows that all firms pay the same price for use of factors of the same type. Among the assumptions which lead to the usual results are that private factors are identical, there are many sellers of private factors, and exit and entry into the market is free.

In the case of a public factor, such as noise disturbance, it seems reasonable to keep the latter two assumptions. Many firms and sellers take part in the artificial market set up by the NCB, and entry and exit into the market is free. However, the noise disturbances of individual firms such as r^g_{m+p} and r^f_{m+p}, $g\neq f$, are not generally identical in the sense that, unless $\partial R_{m+p}/\partial r^f_{m+p}= \partial R_{m+p}/\partial r^g_{m+p}$, increments to r^f_{m+p} and r^g_{m+p} result in different increments to aggregate noise abatement r_{m+p}. Since it is aggregate noise disturbance r_{m+p} which enters the utility functions of individuals directly, the theoretically correct valuation of r^f_{m+p} depends on the increment to r_{m+p} which results from an increment to r^f_{m+p}. This increment is given by the function $\partial R_{m+p}/\partial r^f_{m+p}$ and depends on the absolute level of r^f_{m+p}. For any individual, the marginal cost of an increment to r_{m+p} is given by wh^h_p, a price which depends on the absolute level of r_{m+p}. Hence, the correct cost to this individual of an increment to r^f_{m+p} is given by

$$wh^h_p \times \frac{\partial R_{m+p}}{\partial r^f_{m+p}}.$$

The sum of all such valuations over every individual gives the marginal cost of an increment to r^f_{m+p}. This is the sum that is defined in equation (13).

This discussion shows that prices paid by firms for own noise disturbance, given by equation (13), need not be equal. However, the price paid by the firm for an increment to aggregate noise disturbance is equal for every firm.

Zero Profits and the NCB

If the NCB does not make a profit, then total payments received from firms must equal total payments to individuals by the NCB. This condition is given by the sum of scalar products.

$$(33) \qquad \sum_{p=1}^{P} w_p \, r_{m+p} = \sum_{p=1}^{P} \sum_{f=1}^{F} wf_p^f \, r_{m+p}^f$$

$$\text{where } w_p = \sum_{h=1}^{H} wh_p^h$$

But wf_p^f is given by the sum of scalar products

$$(13) \qquad wf_p^f = \left(\sum_{h=1}^{H} wh_p^h \right) \frac{\partial R_{m+p}}{\partial r_{m+p}^f} = w_p \frac{\partial R_{m+p}}{\partial r_{m+p}^f}$$

Thus, (33) can be rewritten as

$$(34) \qquad \sum_{p=1}^{P} w_p r_{m+p} = \sum_{p=1}^{P} \sum_{f=1}^{F} w_p \frac{\partial R_{m+p}}{\partial r_{m+p}^f} r_{m+p}^f =$$

$$\sum_{p=1}^{P} \sum_{f=1}^{F} w_p \, r_{m+p} \frac{\partial R_{m+p}}{\partial r_{m+p}^f} .$$

Dividing both sides of (34) by the scalar w_p yields,

$$(35) \qquad \sum_{p=1}^{P} r_{m+p} = \sum_{p=1}^{P} \sum_{f=1}^{F} r_{m+p}^f \frac{\partial R_{m+p}}{\partial r_{m+p}^f}$$

Equation (35) can be interpreted to mean that the requirement of zero profits and efficient pricing for the NCB implies that in equilibrium the sum of aggregate noise disturbance over all locations $p=1,2,\ldots,P$ is a weighted sum of noise disturbance r_{m+p}^f of every firm $f=1,2,\ldots,F$ at every location $p=1,2,\ldots,P$. The weights are the respective marginal products of each noise disturbance r_{m+p}^f in the production of aggregate noise disturbance r_{m+p}. The sum on the left of (35) is, obviously, a measure of economy-wide aggregate noise disturbance.

We shall now demonstrate that if all profits accruing to firms are divided between individuals, then equation (33) is satisfied. First, we sum all the real valued budget constraints over $h=1,2,\ldots,H$; this yields the real valued equation

$$(36)\quad w.\left(\sum_{h=1}^{H} r_1^h, \sum_{h=1}^{H} r_2^h, \ldots, \sum_{h=1}^{H} r_m^h\right) + \left(\sum_{h=1}^{H} wh_1^h, \sum_{h=1}^{H} wh_2^h, \ldots,\right.$$

$$\left.\sum_{h=1}^{H} wh_p^h\right).\ r_p + \left(\sum_{h=1}^{H} s_1^h, \sum_{h=1}^{H} s_2^h, \ldots, \sum_{h=1}^{H} s_F^h\right).\ \Pi = p.\left(\sum_{r=1}^{H} c_{.}, \sum_{h=1}^{H} c_2, \ldots,\right.$$

$$\left.\sum_{h=1}^{H} c_n\right).$$

Let us define

$$(37a)\quad c_j = \sum_{h=1}^{H} c_j^h = \sum_{f=1}^{F} c_j^f \qquad j=1,2,\ldots,n$$

$$(37b)\quad r_i = \sum_{h=1}^{H} r_i^h = \sum_{f=1}^{F} r_i^f \qquad i=1,2,\ldots,m.$$

Recall the definition of w_p in (33) and that $\sum_{h=1}^{H} s_f^h = 1$ from (6), and using (37), write (36) as

$$(38)\quad w.(r_1, r_2, \ldots, r_m) + (w_1, w_2, \ldots, w_p).r_p + (1,1,\ldots,1).\ \pi$$

$$= p.\ (c_1, c_2, \ldots, c_n),$$

Now the inner product of vectors $(1,1,\ldots,1).\ \pi$ yields the scalar sum $\sum_{f=1}^{F} \pi f$. Using equation (9) we write the real valued equation

$$\sum_{f=1}^{F} \pi f = p.(\sum_{f=1}^{F} c_1^f, \sum_{f=1}^{F} c_2^f, \dots, \sum_{f=1}^{F} c_n^f) - w.(\sum_{f=1}^{F} r_1^f, \sum_{f=1}^{F} r_2^f \dots \sum_{f=1}^{F} r_m^f) - \sum_{f=1}^{F} (wf_p^f . r_p^f), \tag{39}$$

or using (37a) and (37b),

$$\sum_{f=1}^{F} \pi f = p.(c_1, c_2, \dots, c_n) - w.(r_1, r_2, \dots, r_m) - \sum_{f=1}^{F} (wf_p^f . r_p^f). \tag{40}$$

Now substitute the right hand side of (40) for $\sum_{f=1}^{F} \pi_f$ in (38) and cancel like terms: this gives

$$(w_1, w_2, \dots, w_P).r_p - \sum_{f=1}^{F} (wf_p^f . r_p^f) = 0. \tag{41}$$

Taking the indicated inner products of vectors and transposing yields

$$\sum_{p=1}^{P} w_p \, r_{m+p} = \sum_{p=1}^{F} \sum_{f=1}^{P} wf_p^f \, r_{m+p}^f . \tag{42}$$

Since the terms of the sum on the right hand side are commutative scalar products, we may write equation (42) as

$$\sum_{p=1}^{P} w_p \, r_{m+p} = \sum_{p=1}^{P} \sum_{f=1}^{F} wf_p^f \, r_{m+p}^f \tag{33}$$

This shows that equation (33) is always satisfied if profits are divided among individuals.

The Pareto Equivalence of Producers' Rights and Consumers' Rights

In Section D, it was asserted that producers' rights and consumers' rights both determine efficient equilibrium levels of aggregate noise abatement. We adopted the consumers' rights case and implicitly chose a level of zero aggregate noise disturbance as a benchmark from which the magnitude of r_{m+p} is measured.

We now examine the producers' rights position. Individuals have to pay for the noise abatement activity of firms. We define aggregate noise abatement as a public good. Suppose we have an aggregate noise abatement function C_{m+p},

(43a) c_{n+p}=aggregate noise abatement at location p

(43b) c^f_{n+p}=noise abatement of firm f at location p,

(43c) $c_{n+p}=C_{n+p}(c^1_{n+p},c^2_{n+p},\ldots,c^F_{n+p})$

where $p=1,2,\ldots,P$.

The abatement function C_{n+p} is assumed to have all of the nice properties of the disturbance function R_{m+p}, given by equation (2c′). Implicit in this definition is the assumption that a measurement of noise abatement activity by firm f is meaningful. This implies that the level of noise disturbance that would be produced by firm f in the absence of NCB regulatory action is known as a benchmark from which the level of noise abatement c^f_{m+p} is measured. Let the benchmark be denoted by N^f_p. Thus,

(44) $r^f_{m+p}+c^f_{n+p}=N^f_p \quad f=1,2,\ldots,F, \quad p=1,2,\ldots,P.$

N^f_p is a constant. In equation (44), r^f_{m+p} may be interpreted both as the difference between the benchmark N^f_p and the firm's noise abatement activity c^f_{n+p}, and as the firm's use of noise disturbance rights. In a producers' rights scheme, r^f_{m+p} is the residual, while in a consumers' rights scheme, the firm purchases r^f_{m+p}, and c^f_{n+p} is the residual.

We combine the disturbance function R_{m+p} and the abatement function C_{n+p} to define a benchmark for the level of aggregate noise disturbance in the absence of an artificial market.

$$(45)\quad R_{m+p}(r^1_{m+p},r^2_{m+p},\ldots,r^F_{m+p})+C_{n+p}(c^1_{n+p},c^2_{n+p},\ldots,c^F_{n+p})=$$

$$N_p(N^1_p,N^2_p,\ldots,N^F_p)=N_p \qquad p=1,2,\ldots,P.$$

Since N^f_p is constant for all f, N_p is also a constant.

Utility and production functions are re-defined to be consistent with producers' rights. Thus, (7) becomes

$$(46)\quad U_h=(c^h;c_p;r^h_o-r^h) \qquad h=1,2,\ldots,H$$

where $c_p=(c_{n+1},c_{n+2},\ldots,c_{n+P})$;

and (10) becomes

$$(47)\quad F_f(c^f;c^f_p;r^f)=0 \qquad f=1,2,\ldots,F$$

where $c^f_p=(c^f_{n+1},c^f_{n+2},\ldots,c^f_{n+P})$.

From equations (44) and (45), it follows that

$$(48)\quad \frac{\partial R_{m+p}}{\partial r^f_{m+p}} = \frac{\partial N_p}{\partial r^f_{m+p}} - \frac{\partial C_{n+p}}{\partial r^f_{m+p}} = -\frac{\partial C_{n+p}}{\partial c^f_{n+p}} \frac{\partial c^f_{n+p}}{\partial r^f_{n+p}} = \frac{\partial C_{n+p}}{\partial c^f_{n+p}}$$

because $\partial N_p/\partial r^f_{m+p} = 0$ and $\partial c^f_{n+p}/\partial r^f_{m+p} = -1$. Likewise,

$$(49) \quad \frac{\partial F_f}{\partial r^f_{m+p}} = \frac{\partial F_f}{\partial c^f_{n+p}} \; \frac{\partial c^f_{n+p}}{\partial r^f_{m+p}} = -\frac{\partial F_f}{\partial c^f_{n+p}}$$

$$(50) \quad \frac{\partial U_h}{\partial c_{n+p}} = \frac{\partial U_h}{\partial r_{m+p}} \; \frac{\partial r_{m+p}}{\partial c_{n+p}} = -\frac{\partial U_h}{\partial r_{m+p}} \; .$$

Since $\partial c^f_{n+p}/\partial r^f_{m+p} = \partial r_{m+p}/\partial c_{n+p} = -1$.

A Pareto efficiency criterion for the public factor market is given by equation (16). We now derive a Pareto efficiency criterion for the public goods market from equation (16). Use (50) on the left hand side of (16):

$$(51) \quad \sum_{h=1}^{H} \frac{\partial U_h/\partial r_{m+p}}{\partial U_h/\partial r^h_i} = -\sum_{h=1}^{H} \frac{\partial U_h/\partial c_{n+p}}{\partial U_h/\partial r^h_i} \qquad \begin{array}{l} i=1,2,\ldots,m \\ p=1,2,\ldots,P \end{array}$$

Likewise, use (49) and (48) on the right hand side of (16) to obtain

$$(52) \quad \frac{\partial F_f/\partial r^f_{m+p}}{\partial F_f/\partial r^f_i} \cdot \frac{1}{\partial R_{m+p}/\partial r^f_{m+p}} = -\frac{\partial F_f/\partial c^f_{n+p}}{\partial F_f/\partial r^f_i} \; \frac{1}{\partial C_{n+p}/\partial c^f_{n+p}}$$

for $i=1,2,\ldots,m$; $p=1,2,\ldots,P$.

Together, equations (16), (51) and (52) imply

$$(53) \quad \sum_{h=1}^{H} \frac{\partial U_h/\partial c_{n+p}}{\partial U_h/\partial r^h_i} = \frac{\partial F_f/\partial c_{n+p}}{\partial F_f/\partial r^f_i} \; \frac{1}{\partial C_{n+p}/\partial c^f_{n+p}} \; .$$

It will be stated without proof that the corresponding Pareto efficiency criterion for the public goods market derived from (46), (47) and appropriate profit and budget equations (derived using the methodology of Section F), is given by

$$(54)\quad \sum_{h=1}^{H} \frac{\partial U_h/\partial c_{n+p}}{\partial U_h/\partial r_i^h} = \frac{\partial F_f/\partial c_{n+p}^f}{\partial F_f/\partial r_i^f} \; \frac{(-1)}{\partial C_{n+p}/\partial c_{n+p}^f} \; .$$

Conversely, it can be shown, by the reader, that equations (54), (51) and (52) imply equation (16), except for a sign change. Hence, except for a sign change and given (51) and (52), the criterion for Pareto efficiency in the public factor market is satisfied if and only if the criterion for Pareto efficiency in the public goods market is satisfied. The sign change can be interpreted to mean that the criteria are mutually exclusive, in the sense that one and only one holds, but either yields Pareto efficiency. Thus, consumers' rights and producers' rights are equivalent with respect to Pareto efficiency, but a choice has to be made between then.

The sign change results from a change in the flow of costs and benefits determined by the choice between consumers' rights and producers' rights. In the case of consumers' rights aggregate noise disturbance r_{m+p} is a social cost, and thus, the left hand side of (16) denotes the marginal cost (MC_p) of r_{m+p}, while in the producers' rights case, aggregate noise abatement c_{n+p} is a social benefit, and thus the left hand side of (54) is the marginal benefit (MB_p) of c_{n+p}. In the former case, costs flow to the individual because r_{m+p} is produced, while in the latter case, benefits flow to the individual because c_{n+p} is produced.

The equilibrium interpretation of equation (54) is that the sum of the marginal rates of substitution of every individual (MRS_h) of c_{n+p} for an arbitrary private factor (taken as numeraire) denotes the marginal benefit to society of an increment to c_{n+p} (MB_p); the right hand side of (54) denotes the firm's marginal cost[25] of producing an increment to aggregate noise abatement c_{n+p}, in terms of the i_{th} private factor. Since (54) holds for all $f=1,2,\ldots,F$, we have $MB_p=MC_p^f$ for all f, and thus, $MC_p=MC_p^1=\ldots=MC_p^F$. This shows that the marginal benefit of aggregate noise abatement everywhere just equals its marginal cost of production. In other words, if the Pareto efficiency criterion (54) holds, then the following equality is satisfied,

$$(56)\quad MB_p=\sum_{h=1}^{H} MRS_h=MC_p.$$

We now show that the price to be paid firms for a unit of noise abatement is just the negative of wf_p^f, as defined in equation (13). The negative sign means that the direction of flow of payment has changed from firm-to-individual to individual-to-firm (via the NCB). Combining (51) and (23) gives

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[25] Compare this interpretation of left and right hand sides of (54) to the interpretation of left and right hand sides of (16) given in this Section, Equality of Cost and Benefit of r_{m+p}.

$$(57)\quad \sum_{h=1}^{H} \frac{\partial U_h/\partial c_{n+p}}{\partial U_h/\partial r_i^h} = -\sum_{h=1}^{H} wh_p^h \text{ .}$$

This means that the sum of willingness-to-pay prices over all individuals for an increment to c_{n+p} is equal to the negative of the sum of their selling prices for r_{m+p}. Take the negative of equation (13), and use the equality in (48) to write

$$(58)\quad \sum_{h=1}^{H} (-wh_p^h) \frac{\partial C_{n+p}}{c_{n+p}^f} = \sum_{h=1}^{H} (-wh_p^h) \frac{\partial R_{m+p}}{\partial r_{m+p}^f} = -wf_p^f .$$

In view of (57), equation (58) may be interpreted to mean that the efficient price for firm f's noise abatement c_{n+p}^f is equal to the product

summed individual willingness-to-pay prices for aggregate noise abatement c_{n+p} x marginal product of firm's own noise abatement c_{n+p}^f in the production of aggregate noise abatement.

The theoretical equality of the magnitudes of the price paid to firms for noise abatement and the price paid by firms for noise disturbance suggests a procedure for testing the accuracy of willingness-to-pay estimates inferred from random sample survey data. Two different surveys should be administered by the NCB to two different random samples drawn from the target population. The first survey should be designed to elicit data on willingness-to-pay for aggregate noise abatement. The second should be designed to elicit data on supply prices for aggregate noise disturbance. Separate estimates of summed willingness-to-pay and summed selling prices for the target population should be inferred from the data of the two surveys. Theoretically, the difference between the magnitudes of the two estimates should be zero. If an actual nonzero difference results, greater than what would occur by chance, then either (1) the theory presented in this chapter is false, or (2) better survey measures should be devised. However, if the difference is less than what could occur by chance, then the NCB can be reasonably sure that its estimate of summed willingness-to-pay is a good one.

Computation of wf^f_p and the Information Demand.

Inspection of equation (13) shows that the NCB must have complete information on the disturbance function R_{m+p}, including information on the form of all first partial derivatives in order to compute wf^f_p. The first partials $\partial R_{m+p}/\partial r^f_{m+p}$, in turn, are functions depending on absolute magnitudes of r^f_{m+p}, for all $f=1,2,\ldots,F$. The NCB must, therefore, compute efficient levels of r^f_{m+p} for every firm f. This task makes heavy demands on the NCB's information system.

For example, if production functions are nicely behaved, and known to the NCB for all goods and all firms, the NCB can compute the required levels of r^f_{m+p} for all firms. We saw in equations(28) and (27) that

$$(28) \quad wf^f_p = p_j MFf^j_p = p_j \frac{\partial c_j}{\partial r^f_{m+p}} .$$

The partial derivative $\partial c_j/\partial r^f_{m+p}$ is derived from the production function of firm f, say

$$(59)\quad c_j = g_f(r^f\,;\ r^f_p)$$

Where r^f is given by definition (3f) and r^f_p, by (3g'). Thus, (28) can be written

$$(60)\quad wf^f_p = p_j\,\frac{\partial g_f}{\partial r^f_{m+p}}$$

Dividing both sides by $\partial R_{m+p}/\partial r^f_{m+p}$ gives

$$(61)\quad w_p = \frac{p_j(\partial g_f/\partial r^f_{m+p})}{\partial R_{m+p}/\partial r^f_{m+p}} = h_f(r^1_{m+p}, r^2_{m+p}, \ldots, r^F_{m+p})$$

where h_f is a function of all r^f_{m+p}, f=1,2,...,F.

Equation (61) yields a system of F equations in F unknowns. If the Jacobian of this system is nonvanishing, then we can solve the system of F equations

$$(62)\quad r^f_{m+p} = h^{-1}_f\,(w_p) \text{ for } f=1,2,\ldots,F$$

since the nonvanishing Jacobian guarantees the existence of h^{-1}_f. Therefore, the NCB must have prior knowlege of the F production functions g_f defined in (59), in addition to the function R_{m+p}.

H. Conclusion.

The objective of this chapter is to determine efficiency criteria for the abatement of aggregate noise disturbance emanating from many sources. The findings are consistent with the general criterion: the efficient level of aggregate noise abatement is such that the marginal benefit of its provision is just equal to the marginal cost of its production.

A variety of noise control strategies are available which promise to implement this criterion. Among them are tax/subsidy schemes and direct regulation of noise emission levels. This chapter analyzes an excise tax system on the manufacturers of motor vehicles. It appears that this strategy of control minimizes demands on the administrative and information systems required for implementation. If an excise tax system is adopted, the responsible authorities should tax each firm, at a rate per unit of noise disturbance equal to the product

summed individual supply prices for aggregate noise disturbance r_{m+p} x marginal product of firm's own noise disturbance r^f_{m+p} in the production of aggregate noise disturbance.

It is shown in this chapter that these are the only rates, compatible with a competitive system, which equalize marginal benefit and marginal cost. Implementation of these tax rates means that different firms would pay prices for noise disturbance that reflect the contribution of each to the aggregate level of noise disturbance. It is also shown that no competitive price system is efficient unless these rates are charged for noise disturbance.

The information demands of an excise tax system are limited to (1) determination of the noise disturbance function and/or the noise abatement function, (2) the selling price of every individual for aggregate noise disturbance and/or the willingness-to-pay of every individual for aggregate noise abatement, and (3) the production function of every firm. The term "limited" is used to describe these demands only to contrast them to the demands made by other noise emission control schemes. The measurement problems associated with the gathering of the three blocks of information just listed are very great. However, the theory described herein guarantees that if this data can be collected, it can be interpreted and utilized in a socially meaningful way. This theory should serve to focus current information gathering activities aimed at understanding the aggregate noise disturbance phenomenon.

Finally, an hypothesis concerning the equality of summed willingness-to-pay prices and summed selling prices is posed. Estimates of these two magnitudes for the target population should be inferred from data of different random surveys designed to elicit each. The likelihood of obtaining a non-zero difference between the two estimates can be tested for statistical significance. If this difference is sufficiently close to zero, then the estimate of summed willingness-to-pay is probably accurate. As we have seen, this figure is required for the calculation of noise disturbance prices of tax rates.

CHAPTER IV

DISCUSSION OF THE QEI QUESTIONNAIRE ON NOISE POLLUTION

A. Introduction

The questionnaire designed by QEI, Incorporated to elicit responses on costs of urban noise is presented in Figure 4.1[1]. This questionnaire was developed in response to Task C of the Statement of Work.

The basic purpose of this QEI Noise Pollution Questionnaire is to determine a typical urban dweller's willingness-to-pay for a specific reduction in noise. This questionnaire is basically an economic type of questionnaire designed to determine people's willingness-to-pay in specific numbers of dollars for specific amounts of noise reduction. When a government agency is attempting to impose standards or regulations to control noise, it is vital that the agency know approximately how much the public is willing to pay for noise reduction. Otherwise, regulations may well be imposed that do not reflect the public's actual desires on controlling noise pollution, as indicated by their willingness-to-pay for noise reduction. If the public's willingness-to-pay for noise control were not known, either regulations would be imposed that were too lax, implying that the public would eventually decide that little had been accomplished by imposing the regulations and that noise was still a problem; or regulations would be imposed that were too strict, implying that a burden would be imposed upon the public that it did not wish to bear. In a democratic society regulations imposed by government agencies should be in accordance with the actual desires of the people.

---

[1] We wish to acknowledge the assistance of Cambridge Survey Research in designing and pretesting this questionnaire.

NOISE POLLUTION QUESTIONNAIRE

PREPARED FOR THE EPA BY QEI

OMB Clearance No. 158-S-75002

Hello, I'm taking a public opinion survey under a contract for the EPA. We're trying to find out how the people of this area feel about some of the problems facing them. I'd like to ask you a few questions on a strictly confidential basis.

1. First of all, how would you rate this neighborhood as a place to live?
   1. Excellent 2. Good 3. Only fair 4. Poor 5. (Don't know)

2. What would you say is the major problem facing this neighborhood today?
   ____

3. Is there anything you particularly like about living here?
   ____

4. Is there anything you particularly dislike, or feel should be changed?
   ____

5. How long have you lived here? (RESPONSE IN NUMBER OF YEARS)
   ____

6. Over that period, do you think the quality of life in the neighborhood has improved, declined, or stayed about the same?
   1. Improved 2. Stayed the same 3. Declined 4. (Don't know)

7. Over the next few years do you think the quality of life in this neighborhood will improve, decline, or stay about the same?
   1. Improve 2. Stay the same 3. Decline 4. (Don't know)

8. About how many hours per day on the average is the radio, or the television set, or the record player or stereo system used?
   ____________ hours

9. What time of day would the radio, or the television set, or the record player typically be used? (MULTIPLE ANSWERS ACCEPTABLE)
   1. Morning 2. Afternoon 3. Evening 4. Night 5. (Don't know)

10. Do you own or rent your home?
    1. Own 2. Rent

11. Do you think you will still be here a year from today or do you think you might move?
    1. Definitely stay (GO TO QUESTION 14)
    2. Might move (CONTINUE IN SEQUENCE)
    3. Definitely will move (CONTINUE IN SEQUENCE)
    4. (Don't know - - GO TO QUESTION 14)

Figure 4.1 - 1

QEI NOISE POLLUTION QUESTIONNAIRE

12. (If #2 or #3) What would your major reason be for making a move?

____

13. Would you move to another part of this neighborhood, to another part of the Boston metropolitan area or to another state?
    1. Another part of neighborhood
    2. Another part of Boston metro area
    3. Another state
    4. (Don't know)

(INTRODUCTION TO QUESTION # 14 FOLLOWS.)

PLEASE LOOK AT THIS CARD. On it is a ladder with rungs numbered zero to ten. I'm going to read you a list of common problems. If you feel the problem very seriously affects you personally in this neighborhood, you would rate it "10" on the ladder -- "very important". If you are not personally affected at all by the problem you would rate it "zero". If you feel it is somewhat important or somewhat serious, you would put it on one of the intermediate rungs of the ladder. Now where would you rate:

14. Robbery and break-ins
15. Street crime and violence
16. Air pollution
17. Noise
18. Dirt and litter
19. Traffic and congestion

20. Overall, how noisy would you say your neighborhood is?
    1. Very noisy 2. Noisy 3. Not bad 4. Quiet 5. Very quiet

21. Are there any particular sources of noise in this neighborhood that annoy you?
    1. Yes -- What? ____________________________
    2. No

22. Which of these statements best describes noise around here?
    1. I am frequently bothered and disturbed by noise problems.
    2. I sometimes notice noise problems around here.
    3. I think noise is not really a problem around here.
    4. (Don't know)

23. How about within your house; would you say your house is:
    1. Very noisy 2. Noisy 3. Not bad 4. Quiet 5. Very quiet

Figure 4.1 - 2

QEI NOISE POLLUTION QUESTIONNAIRE

LET'S LOOK AT THIS LADDER CARD. Say that "10" means a particular thing is a very annoying source of noise around here, while "zero" means you are never bothered by this source of noise. Now I'm going to read you a list of possible sources of noise and I'd like you to tell me how you feel each affects you personally. First of all, how would you rate:

24. Noise from motor vehicles (IF ZERO " GO TO # 30)
25. Noise from large trucks and buses
26. Noise from small trucks
27. Noise from motor cycles
28. Noise from sports cars
29. Noise from regular automobiles or constant traffic

30. Noise from road construction or repairs
31. Noise from building construction or repairs
32. Noise from railroad trains or trolley cars
33. Noise from nearby business establishments
34. Noise from industrial plants or factories
35. Noise from garbage or trash collection
36. Noise from people in the streets or outside
37. Noise from neighbors
38. Noise from household appliances, especially vacuum cleaners, dishwashers, and lawn mowers
39. On the previous list of appliances. were these primarily your own appliances or those of your neighbors bothering you?
    1. Own 2. Neighbors

40 Taking all the noise problems we've looked at together, where would you put the overall noise problem in the neighborhood: at "10" -- "very annoying"; at "zero" -- "no problem at all"; or someplace in-between?

UNLESS RATING IS "ZERO"

41. Again, taking everything together, would you say whatever noise problem there is here is worse at one particular time of day than others? When?
    1. No time difference 2. Midnight - 6 a.m. 3. 6 a.m. - noon
    4. Noon - 6 p.m. 5. 6 p.m. - midnight 6. (Don't know)

42. Would you say whatever noise problem there is, is worse on weekends or during the week?
    1. No difference 2. Weekends 3. Weekdays 4. (Don't know)

Figure 4.1 - 3

QEI NOISE POLLUTION QUESTIONNAIRE

43. Would you say noise problems are worse in a particular season of the year?
1. Summer 2. Fall 3. Winter 4. Spring 5. (No difference)
6. (Don't know)

44. Would you say noise problems bother you more inside your home or when you are outside?
1. Inside 2. (No difference) 3. Outside 4. (Don't know)

45. Are there particular rooms in your home where noise is more annoying than in others? Which room? Why?

____

---

46. Some people find that the kinds of noise we've been talking about interfere with their lives. Can you think of any ways noise has disrupted your life recently -- any activity it's forced you to stop, for example?

____

I'm going to read you a list of problems that might be caused by noise. Let's use the ladder scale again. "Ten" means it is a very annoying problem to you personally while "zero" means it is not a problem at all. If you have not been bothered at all by the problem in the last year you would rate it "zero".

47. Not being able to enjoy radio, television or records due to other noise
48. Not being able to carry on a conversation or telephone conversation due to noise
49. Being awakened from sleep by noise
50. Has noise ever caused your home to vibrate? How often?
1. Never 2. Once or twice 3. Sometimes 4. Frequently
51. Do you ever work at home ? (IF YES) Has noise around here ever interfered with or interrupted such work? (IF YES) What kind of work was that?
1. No
2. yes --no
3. yes -- yes ________________________________

52. In the last year, have you taken any steps to reduce noise around here?
What were they? ________________________________

53. To avoid noise or get away from it? What were they?

____

I'm going to read you a list of things that people sometimes do, to deal with noise. I'd like you to tell me whether or not you've done any of these in the last year -- frequently, sometimes. once or twice, never.

Figure 4.1 - 4

QEI NOISE POLLUTION QUESTIONNAIRE

54. Closed windows during warm weather to cut out outside noise
55. Raised your voice or shouted to be heard in a conversation
56. Left home or taken a trip, even briefly, to get away from noise
57. Added soundproofing to your home
58. Considered adding soundproofing to your home
59. Turned up the sound on television or radio or records to cover up noise
60. Turned on television, radio or records specifically to cover up noise
61. Complained to neighbors, landlord or the police about noise

62. Have any of your neighbors complained to you concerning noise you were making in the past year? How Often?
1. Never 2. Sometimes 3. Once or twice 4. Frequently

People have different attitudes toward noise in general -- whether or not it is a problem and how serious it is compared to other problems.

63. First of all, do you think noise can harm people's physical health?
1. Yes 2. (Not sure) 3. No

64. How about mental or emotional health, can noise harm them?
1. Yes 2. (Not sure) 3. No

65. IF YES TO EITHER # 63 OR #64 Would you say that noise has harmful effects on physical, emotional or mental health frequently, sometimes or rarely?
1. Frequently 2. Sometimes 3. Rarely 4. (Don't know)

66. Do you think your own physical or emotional health has been affected by noise? How?
1. No
2. Yes -- (Don't know)
3. Yes -- ____

67. Some people say that too much fuss is being make about noise these days. Let's look at the ladder again and imagine that the top (10) represents a noisy bustling place and the bottom (zero) represents a calm, very quiet place. Where on the ladder do you think you personally would prefer to be?

68. Where on the ladder do you think the average person would prefer to be?

People have a lot of places where they can spend their money. I'd like to ask you a few questions about how you might spend your money?

Figure 4.1 - 5

QEI NOISE POLLUTION QUESTIONNAIRE

RENTERS ONLY

69. In which of the following categories is your monthly rent?

1. $100 - $124.99
2. $125 - $149.99
3. $150 - $174.99
4. $175 - $199.99
5. $200 - $224.99
6. $225 - $249.99
7. $250 + Per Month

#________________

70. Now let's look at this card (SAME AS QUESTION #40) where you rated the noise level in this neighborhood. Let's say we could lower the noise level one step, either by the government setting new standards for noise or by your purchasing some noise reducing device. Everything else about the place and neighborhood would stay exactly the same, only the noise level would be reduced. About how many extra dollars per month do you think you would be willing to spend for that, if anything?

$________________

71. Now let's say we could lower the noise level three steps. Once more everything else about the place and neighborhood would stay exactly the same, only the noise level would be reduced. About how many extra dollars per month do you think you would be willing to spend for that?

$________________

72. How about if the noise level could be reduced to a level that is never at all annoying; how much extra money per month would you be willing to pay for that, if anything?

$________________

HOMEOWNERS ONLY

73. In which of the following categories is your estimate of the worth of this home, if you were to sell it today?

1. $10,000 - $14,999
2. $15,000 - $19,999
3. $20,000 - $24,999
4. $25,000 - $29,999
5. $30,000 - $34,999
6. $35,000 - $39,999
7. $40,000 - $44,999
8. $45,000 - $49,999
9. $50,000 +

#________________

Figure 4.1 - 6

QEI NOISE POLLUTION QUESTIONNAIRE

74. In which of the following categories is your present monthly property tax payment against your semi-annual property tax bill?

1. $0 - $ 49.99   2. $ 50.00 - $ 99.99
3. $100.00 - $149.99   4. $150.00 - $199.99
5. $200.00 - $249.99   6. $250.00 - $299.99
7. $300.00 - $349.99   8. $350.00 +

#________________

75. Now let's look at this card (SAME AS QUESTION #40) where you rated the noise level in the neighborhood. Let's say we could lower the noise level by one step, either by the government setting new standards for noise or by your purchasing some noise reducing device. Everything else about the place and neighborhood would stay exactly the same; only the noise level would be reduced. About how many extra dollars per month do you think you would be willing to pay on your monthly property tax payment, if anything?

$________________

76. Now let's say we could lower the noise level three steps. Once more everything else about the place and neighborhood would stay exactly the same; only the noise level would be reduced. About how many extra dollars per month do you think you would be willing to pay on your monthly property tax payments, if anything?

$________________

77. How about if the noise level could be reduced to a level that is never at all annoying; how much money per month would you be willing to pay for that on your monthly property tax payment, if anything?

$________________

---

78. How concerned are you about the current economic situation?

1. Very concerned   2. Somewhat concerned
3. Slightly concerned   4. Not at all concerned

79. How much would your concern with the present economic situation affect your willingness-to-pay for noise reduction?

1. Very much   2. Somewhat
3. Not too much   4. Not at all

Figure 4.1 - 7

QEI NOISE POLLUTION QUESTIONNAIRE

To complete the analysis for this survey, we would like some additional information about your background.

80. What is your age? (record years)

____

81. What was the last grade you completed in school?

1. Some grade school (1-8)
2. Some high school (9-11)
3. Graduated high school
4. Technical or vocational school
5. Some college
6. Graduated college
7. Post-college, graduate or professional study

#_________________

82. Are you the principal wage-earner in this household or is someone else? _______ (IF SOMEONE ELSE) What was the last grade (he/she) completed in school?

1. Some grade school (1-8)
2. Some high school (9-11)
3. Graduated high school
4. Technical or vocational school
5. Some college
6. Graduated college
7. Post-college, graduate or professional study

#_________________

83. (CHOOSING FROM THIS LAST QUESTION) What is (your/the principal wage-earner's) Occupation?

1. (Employed full-time)
2. (Employed part-time)
3. (In temporary employment)
4. (Self-employed)
5. (Unemployed)
6. (retired)
7. (A Student)
8. (On Welfare)
9. (Other - Specify____

84. (IF 1,2,3,4 TO ABOVE) What kind of organization does (he/she) work for? What kind of service or product does it produce?

____

85. (IF 1,2,3,4 TO #83) What kind of job does (he/she) have?

____

86. How many rooms, not including bathrooms, are there in this house or apartment?

____

87. How many children under 18 years of age and living at home are there in your family?

____

Figure 4.1 - 8

QEI NOISE POLLUTION QUESTIONNAIRE

88. Do you have air-conditioning?

1. Yes 2. No 3. (Partial - in some rooms)

#________________

89. Do you have double or thermo-pane windows, or do you just have a single pane of glass?

1. Double 2. (Not sure) 3. Single

#________________

90. In which of the following categories is your total family income?

1. $0-$4,999 2. $5-$9,999 3. $10-$14,999 4. $15-$19,999
5. $20-$24,999 6. $25,000+ 7. (Refused)

#________________

THANK YOU!

Address________________________________ Phone________________

Interviewer I.D.________________________________

91. Sex

1. Male 2. Female

92. Race

1. White 2. Black 3. Other

93. Type of home:
1. Detached - single family
2. Duplex
3. Single family - row or attached
4. Apartment - less than 4 floors or 40 units
5. Apartment - more than 4 floors or 40 units
6. Mobile home
7. (Other - specify________________________________)

94. (IF 4 or 5 TO ABOVE) Floor on which respondent lives ________

95. d B(A) Reading

Analytic data: (Not interviewer-available)

96. Distance from Nearest Point of Airport or Flight Path

Figure 4.1 - 9

QEI NOISE POLLUTION QUESTIONNAIRE

97. Distance from Nearest Point of Super Highway (number of lanes on the nearest super highway should be noted if possible, number of heavy trucks per minute moving along the highway, also)

98. Distance from Nearest Point of Rapid Transit Line or Railroad

99. Distance from Nearest Construction project (possibly) (Size of construction project and number of air compressors, generators, etc. at the construction site should be noted)

100. One of the following: Census Tract population density/ or / people per room ratio/ or /average housing value/ or /some combination of objective census facts.

Figure 4.1 - 10

QEI NOISE POLLUTION QUESTIONNAIRE

NOISE POLLUTION LADDER CARD

10-----------------------------------Very Annoying

9-----------------------------------

8-----------------------------------

7-----------------------------------Rather Annoying

6-----------------------------------

5-----------------------------------

4-----------------------------------

3-----------------------------------Somewhat Annoying

2-----------------------------------

1-----------------------------------A Little Annoying

0-----------------------------------Not At All Annoying
No Problem At All

Figure 4.1 - 11

It is, of course, assumed that the annoyance caused people by excessive noise and thus their willingness-to-pay for its reduction are highly correlated with some observable physical measurement of noise intensity. If this assumption is proven false, there will be no way of imposing noise standards so that the desires of the public are fulfilled. Any noise control standards or regulations that are imposed must, of course, be stated in terms of some directly measurable quantity such as a physical measurement of noise intensity. The assumption that there is a high correlation between annoyance caused by noise and some physical measurement of noise intensity is, of course, basic to the justification for taking such a survey as this. This assumption does, however, seem to be justified by certain other research such as that reported in the Griffiths and Langdon paper (7) and the Foreman, Emmerson, and Dickinson paper (5).

However, the questions on an individual's willingness-to-pay for noise reduction cannot be asked immediately and must be led into gradually by obtaining people's imprecise general views on how serious noise pollution really is. In addition, this questionnaire includes questions on various secondary, but still important, aspects of noise pollution. One of these secondary aspects is the sources of noise believed to be the most important contributors to the entire noise pollution problem. It is necessary to know the most important sources of noise in order to set standards and regulations for noise in an efficient and effective manner. It is obviously desirable to be able to concentrate on the most important sources of noise pollution when attempting to impose standards for noise control. Questions are also included in the survey on the particular activities of the respondent that noise has often interfered with. It is important to know which activities have been interfered with by noise in order to determine people's general attitudes toward noise pollution in relation to the activities that they deem most desirable. Naturally, questions must be included in the survey on the socio-economic status of the respondent in order to test various hypotheses about the relative sensitivity of different classes of people to noise.

This questionnaire should also include questions which will indicate if the respondents are answering the questionnaire under any constraints limiting their willingness-to-pay for noise reduction. One constraint on people's willingness-to-pay for noise reduction is certainly lack of available funds; so therefore questions are asked about the respondents' total family income. A second constraint would appear to be how much the respondents have already spent on noise averting devices. If they have already installed an air conditioner or double pane glass in their windows, they will certainly be much less willing to spend more for noise reduction. This is in part due to the fact that by purchasing and using these noise-reducing devices, they have certainly reduced their problems with noise pollution. This is also due in part to the fact that purchases of noise-reducing devices have depleted their available funds. Thus, the respondents are asked if they have an air conditioner or double pane glass in their windows. A third constraint on the respondents' willingness-to-pay for noise reduction might be the principal source of the noise. If some of the respondents believe that the source of noise that is causing them the most annoyance is basically uncontrollable, they would be less willing to pay for noise control. (Such an uncontrollable noise source might be children.) Once these constraints on the respondents' willingness-to-pay are recognized, they can be taken into account in the analysis.

The most important group of questions in the survey, those relating to people's willingness-to-pay for a specific reduction in total noise - were devised by QEI personnel and consultants during the course of this contract. The other questions in our survey were inspired in part by questions asked in other surveys on noise pollution. The following sources for surveys were particularly important in providing inspiration in designing our secondary questions: 1)Bolt, Beranek, and Newman, "The E.P.A. 24 Site Survey Questionnaire", Spring, 1974; 2) Bolt, Beranek, and Newman, Feasibility of a Novel Technique for Assessing Noise-Induced Annoyances, September, 1973; and 3) Wyle Laboratories, A Program for the Measurement of Environmental Noise in the Community and Its Associated Human Response, Volume II, December, 1973.

The following pages present a discussion of the various groups of questions in the QEI Noise Pollution Questionnaire, taken in the sequence in which they appear in the questionnaire. This discussion will elucidate the reasons for including these particular questions in the questionnaire, and will indicate the relevance of each question to the general topic of noise pollution. The discussion will also contain indications of the uses to which the answers to these questions will be put in any subsequent analysis of the responses to the survey.

B. General Questions on Attitudes Toward Noise

Questions 1-4 are general questions about the environment in which the respondent lives. Hopefully these questions will elicit some general indication from the respondent as to the seriousness of noise pollution in his neighborhood. It is believed that many of the respondents who are very annoyed by noise pollution will mention noise as a problem in response to these questions. These questions should give an indication of the importance of noise to the respondents relative to other environmental problems.

Question 5 attempts to determine how long the respondent has lived in that particular neighborhood. There is some evidence which indicates that people who have lived in a neighborhood for a substantial period of time are more annoyed by noise of a certain intensity and frequency of occurrence than are people who have only recently moved to the neighborhood. For instance, the Rylander, Sorenson, and Kajland survey indicated that the percentage of people who had lived in a neighborhood for more than ten years and who were "very annoyed" at noise of a certain intensity was four times the percentage of people who had moved to the neighborhood within the last year and who were "very annoyed". (See Ref. 8, pp. 432-433). This seeming increase in annoyance at noise pollution with increasing length of stay in a neighborhood appears to be due to a person's increasing commitment to a neighborhood and increasing unwillingness to leave as his length of stay in the neighborhood grows. Thus, one of the reasons for asking this question is to determine how much a person's willingness-to-pay for a specific reduction in noise pollution is affected by the length of his stay in a particular neighborhood. Also, it is usually believed that the rate at which people move into and out of a neighborhood is a good indicator of the stability and continuity of the neighborhood. An approximation to the rate of housing turnover for a particular neighborhood could be calculated by taking the average of all the responses to this question for a neighborhood. Thus, the responses to this question might be manipulated to yield a basic socio-economic indicator (to be used in the following analysis) for some of the neighborhoods surveyed, anyway.

Questions 6-7 are general questions asked to determine how people think their entire environment is changing over time. Hopefully these questions will indicate the respondent's basic view of their future environment. Question 7 should determine whether the respondents are basically optimistic or pessimistic about their future environment and question 6 should indicate a part of the basis for their optimism or pessimism, respectively.

Questions 8-9 are asked to determine how often most of the noise pollution around a person is being blanked out, either because of a conscious or unconscious desire to eliminate the unwanted noise or because of a conscious desire to listen to some sort of entertainment. It was believed that it was unimportant to distinguish among sound produced by radio, television, or record player for the purposes of this survey, since we only wish to learn how often people regularly blank out noise.

Question 10 is a request for a basic piece of information about the respondent (does he own his home or not) which will determine the basic form in which the questions on his willingness-to-pay for noise reduction will be asked. It is also of interest to determine if ownership of one's home affects one's willingness-to-pay for noise reduction.

Questions 11-13 constitute another method of determining the respondent's general level of satisfaction with his total environment. Thus, the answers to these questions should provide something of a cross-check on the answers given to questions 1-4. The answers to these questions for a group of respondents from the same neighborhood will also give an indication of the basic stability of the neighborhood, which is an important socio-economic variable, as was mentioned above.

Questions 14-19 will force the respondents to compare the annoyance caused them by noise with the annoyance caused by other environmental menaces or nuisances. These questions should elicit a specific indication as to approximately how important the respondents consider noise in relation to other environmental hazards. Up to this point no questions have been asked specifically about noise. The basic purpose of avoiding questions specifically on noise initially is to induce the respondents to give an unbiased estimate of how annoying noise really is to them. Those respondents who believe that noise is a very serious problem and are very much annoyed by it are given the opportunity to bring up noise by themselves, thereby indicating their great concern over this type of pollution. It was believed that indicating that noise was our principal concern would bias people's initial responses on what they considered to be the most annoying environmental problems in their neighborhoods. It was hoped that people would respond with their true normal reactions to noise if the questions were asked in this manner, rather than trying to please the interviewer or discourage and get rid of him. It should be made clear that this manner of asking questions does not involve deceiving the respondents or persuading them to say things that they do not really mean.

In questions 20-23 the respondents are finally asked specifically about their reactions to noise, following the gradual lead-in to questions on noise. These four questions are general questions concerning the annoyance caused the respondents by noise. It should be noted that these four questions contain a certain amount of cross-checking within themselves. Also, the responses to these questions can be cross-checked against the responses to earlier questions, particularly questions 1-4 and 17.

Questions 24-39 attempt to determine the relative importance of the various sources of noise to the respondent. The answers to these questions should indicate which sources of noise pollution it is most desirable to regulate and control, assuming, of course, that the sources of noise pollution which should be controlled are those which cause people the most annoyance. The Foreman, Emmerson, and Dickinson survey (5) conducted in London and Woodstock, Ontario, indicated that motorcycles were the most bothersome source of noise, and it would be interesting to confirm or dispute this finding. The respondents are aksed only one question about noise sources, such as pets, children, and adult neighbors (talking, fighting, having noisy parties) since laws regulating such noise sources would be very difficult to have adopted and would be virtually impossible to enforce. Specific instances of noise from such sources might be (and sometimes are) controlled, but any such control would have to proceed on a case-by-case basis. Thus, since information obtained about such noise sources could not be readily used to set standards or regulations, it seemed pointless to ask questions about these sources. Questions are not asked about noise sources such as aircraft and airports since these sources were covered by similar contracts.

Questions 40-41 are general questions on the annoyance caused by all sources of noise taken together. Since these questions relate to the level of annoyance caused by noise from all sources, they constitute a cross-check on other questions on this issue, particularly questions 20-23.

Questions 42-43 bear on the problem of determining the seasonal period or duration of sampling as mentioned in Task E of the Statement of Work. Determining when such a noise pollution survey as this should be taken and determining if return visits to the original respondents at a later time are desirable is a difficult problem, due to the variations in both overall noise level and the vulnerability of people to noise over the course of a year. (It is assumed that people's more recent experiences impress them more than experiences that occurred a long while ago.) Other than the problems caused in sampling due to the variations in the effects of noise over time, these variations raise considerable problems in determining how to combine samples of public reactions to noise taken at different times or how to take account of these variations when dealing with a sample taken at one particular time.

Questions 44-45 pertain to the spatial distribution of noise in and around the respondent's home. Question 44 should also provide a cross-check on question 43.

Questions 46-51 attempt to ascertain the activities of the respondent that noise interferes with, and the seriousness or extent of such interference. Initially, the respondents are asked to name activities that noise has often interfered with. Then, a specific activity is mentioned and the respondent is asked if noise has interfered when he has been engaged in that particular activity, and how frequent such interference with this activity has been. This method of asking the respondent to name activities that noise has interfered with and then asking him particularly about various activities noise could interfere with should expose more of the respondent's actual feelings on this topic. The response to question 46 will provide something of a cross-check on the responses to questions 47-51. Rest and relaxation (inside or outside) are not included in the list of specific activities that the respondent is questioned about since it is dubious that the effect of noise on them is much different from its effect on many other activities such as cleaning the house, preparing meals, or weeding the garden. It seemed unnatural to single out rest and relaxation from among a group of activities on which noise would have very similar effects. Conversation (and the other activities on which the respondent is specifically questioned) are very different in that transmission of sound is involved. (The basic list of activities that noise might interfere with was derived from the Wyle Laboratories survey (9)).

Questions 52-62 pertain to things the respondents might have done recently to reduce noise around the home or to avoid it. Once more the technique is used of initially asking the respondent to name actions he has performed to reduce noise around his home or avoid it; then a list of actions that are often performed to reduce noise or avoid it is read and the respondent is asked how often he has done these specific things. It is hoped that this method might best elicit the respondent's true response to noise. Questions 52-53 should provide something of a cross-check on questions 54-62.

Questions 63-66 pertain to the respondent's attitude toward the effects of noise on people's physical, mental and emotional health. While the effects of noise on people's physical, mental and emotional health are only one aspect or part of the total problem caused by noise pollution, they are certainly a very important part. People's annoyance with noise pollution is certainly in part an expression of, or a reflection of, their beliefs about the effects of noise on their health and on that of other people. The survey taken by Foreman, Emmerson and Dickinson (5) found that some 30% of the respondents believed that excessive noise had some deleterious effect on people's health. It should be noted that this survey was taken in a relatively small urban area - London and Woodstock, Ontario - so that it might well be that in a large urban area, a much larger percentage of people would be concerned about the effects of noise on health.

Questions 67-68 pertain once more to the respondent's basic attitudes toward noise pollution. As such, these questions constitute a further cross-check on the responses given to questions 20-23.

C. Questions on Willingness-to-Pay for Noise Reduction

Questions 69-77 constitute the principal focus of this questionnaire. These questions attempt to ascertain people's willingness-to-pay for specific reductions in the perceived total noise level. These questions are, of course, based on the assumption that the respondents would engage in no more or no less or no other noise-averting activities than they are presently engaged in, no matter how much the noise level is reduced. (We know approximately how much noise-reducing activity the respondents are presently engaged in from their answers to previous questions on this questionnaire, particularly questions 54-61.) This is, of course, a rather strong assumption, but seems to be virtually necessary to avoid a long explanation to the respondents about noise-averting actions. These questions are divided into two sub-groups, questions 69-72 being designed for those respondents who rent their homes, and questions 73-77 being designed for those who own their homes. This division of respondents into renters and home-owners appeared necessary due to the differing methods of paying rent and paying for home ownership. It also seemed possible that people who own their homes might have a different attitude toward the noise in their neighborhood than those who rent. Both groups of questions, questions 69-72 and questions 73-77 are organized in the same manner and consist of questions that are very similar.

First, the respondents, both renters and homeowners, are asked for an estimate of the amount they pay each month for the use of their home or apartment. (Categories of rent payments and monthly tax payments for owned homes are presented to the respondents since it was believed that they would be more responsive to indicating a range than they would be to giving a precise number of dollars.) Then the respondents are asked how much they would be willing to pay for a reduction of one unit in the annoyance caused them by noise. These questions attempt to determine the respondent's willingness-to-pay for unit reduction in the noise level. Then both groups of respondents are asked how much they would be willing to pay for a reduction of three units in the annoyance caused them by noise. It was believed that there might be certain situations, such as where the noise level was very high, in which a reduction in the noise level by only one unit would make very little difference to the respondent. A unit reduction in noise level might make no appreciable difference to some respondents in certain neighborhoods. Thus, it was decided to ask about a three unit reduction in noise level as well as a one unit reduction, in part, to determine if such situations were prevalent, and, in part, to test the assumption of linearity for people's willingness-to-pay for noise reduction. Lastly, the respondents are asked how much they would be willing to pay for a reduction in noise level to a point where it is never at all annoying. (It is assumed here that annoyance caused by noise and some physical measurement of noise intensity are highly correlated. This assumption seems to be justified by certain other research such as that reported in the Griffiths and Langdon paper (7) or the Foreman, Emmerson, and Dickinson paper (5). Noise regulations must, of course, be stated in terms of some physical measurement of noise.) It should be noted that the respondents will not be forced to say that they would pay anything at all for any reduction in noise pollution, no matter how large. Paying nothing for a reduction in noise pollution is presented to the respondents as an option.

Questions 78-79 represent an attempt to determine how the current economic situation is affecting the respondents' answers to the economically-oriented questions in the survey. It seems very likely that the current recession is having an effect on people's willingness-to-pay for a reduction in the noise level. (Three possible effects on people's willingness-to-pay to reduce the noise level seem possible: 1. the effect caused by the fact that the cost of reducing noise is increasing faster than some people's salaries; 2. the effect caused by fear of future unemployment; and 3. the effect caused by the fact that available housing is becoming hard to find and thus people are prevented from moving to escape excessive noise.) When economic conditions change, the answers received to certain questions on this survey may well change for some respondents. It would be nice to include some indicator of the current economic situation in the analysis of responses to certain questions in this questionnaire (or in any economically-oriented questionnaire). However, substantial research will have to be done to find an appropriate means to insert the answers to questions such as these into an analysis of responses to the willingness-to-pay questions in this questionnaire.

D. Questions on Respondent Characteristics

Questions 80-86 and 90 are included in this survey in an attempt to determine the approximate socio-economic level of each respondent. The socio-economic level of a respondent is determined in part by his income level but also in part by his occupation, amount of education, etc. It is suspected that a person's socio-economic level may well influence his willingness-to-pay for a reduction in the noise pollution level. Persons at higher socio-economic levels might well be more conscious of noise and thus willing to pay larger amounts for its reduction. The answers to these questions might well be used in some sort of analysis, such as a regression analysis, of the answers to the willingness-to-pay for noise reduction questions.

The answer to question 87 will serve to establish in part the approximate ambient noise level in the home, or that level of noise which is usually present in the respondent's home. The answer to question 88 serves to establish the vulnerability of the respondent to noise during the summer, or to indicate a cause for the respondent's annoyance with noise pollution during the summer. The answer to question 89 serves to establish in part the vulnerability of the respondent to noise during the fall, winter and spring, and probably to a lesser degree, during the summer. The response to question 89 will also serve to suggest just how serious the noise problem in the respondent's area really is.

E. General Information on the Respondent

The respondent is only asked to answer questions 1-90. Numbers 91-100 on the questionnaire correspond to information desired about the respondent or his environment which the interviewer is supposed to fill in for each respondent. The respondent should not be asked for the information corresponding to numbers 91-100. The interviewer or his superior should fill in this information for each respondent following the interview.

Numbers 91-93 and 100 will provide basic socio-economic information on the respondent that could be used in an analysis of the respondent's answers to the questions on his willingness-to-pay for noise reduction.

Number 94, the floor on which the respondent resides, if he lives in an apartment house, is very important in determining his vulnerability to ground-level sources of noise pollution, such as vehicular traffic and much construction work. If the respondent lives on one of the upper floors of a high-rise apartment building, he will obviously be very slightly affected by ground-level sources of noise.

Numbers 95-99 request pieces of information which determine to some extent the noise level which is actually present in and typical of the respondent's home. Thus, this information will give us some indication of the actual noise level that the respondent is reacting to. This will be used to determine the respondent's general sensitivity to noise and could be used to identify and possibly separate out people who were abnormally sensitive or abnormally insensitive to noise. The analysis should obviously concentrate on the reactions of normal individuals to noise. The information given here, when organized by neighborhoods, will indicate the most important noise sources in the neighborhoods.

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CHAPTER V

DESCRIPTION OF THE PRETESTING OF THE QEI NOISE POLLUTION QUESTIONNAIRE AND DISCUSSION OF RESULTS

A. Selection of the Sample for the Pretest

The selection of the sample to be tested with the QEI Noise Pollution Questionnaire was performed in accordance with the following general principles. First, it was decided to pretest the instrument on geographical clusters of respondents. Respondents were chosen in such a manner that each respondent lived fairly near nine or ten other respondents. The basic reason for selecting geographical clusters of respondents was to obtain some indication of individual differences among people reacting to the same stimulus or the same level of noise pollution. The variability among individuals reacting to the same noise level seemed an important area to investigate early in the analysis, since if variability among individuals were very high, it might imply that any standards or regulations for noise that could be imposed would be either much too lax or much too strict for most of the population.

Second, it was decided to select the sample to be surveyed largely from areas with a high incidence of traffic noise. The sample was chosen in large part from areas near major highways or important main streets. We wanted to insure a positive response to the questions on this survey, rather than obtaining responses from people who were probably not seriously bothered by noise pollution. This latter group will, of course, be well represented in the sample that will be asked to respond to the final version of the questionnaire; but in performing the pretest we wanted a sample that would allow us to test all the questions in the survey. In performing the pretest we wanted a sample of respondents whose answers would test the upper limits or extremes of the questionnaire.

Third, the sample to be pretested must be chosen from areas that are not affected by noise from aircraft or airports. Noise pollution produced by aircraft or airports will be examined in surveys conducted under similar contracts. Thus, to avoid overlapping with such efforts, areas in which aircraft noise is an important contributor to the total level of noise pollution will not be included among the areas to be surveyed.

For the pretest, it was decided to use a sample of at least 60. It was believed that the answers to a survey of this size would reflect the income variability of the entire Boston SMSA fairly accurately, since the income variable has been restricted on this questionnaire to six mutually-exclusive categories. The variability of income rather than that of some other variable was chosen to determine the sample size for this pretest since income was believed to be the most important determinant of variation in response for this study. The sample size was determined from standard formulas assuming a normal distribution in income.

B. Selected Results of the Pretest

Sixty (60) persons, ten from each of six neighborhoods in the Boston metropolitan area were pretested with the QEI Noise Pollution

Questionnaire. This pretesting indicated that the QEI Noise Pollution Questionnaire does not require any major changes or modifications. All of the questions appeared to be readily comprehensible by the sample of persons pretested. The interviewers indicated that they had no difficulty obtaining reasonable responses from the individuals surveyed to any of the questions included in this questionnaire. However, it does appear that minor modifications might be desirable for three of the included questions.

The distribution of total family income for the persons pretested appears to be approximately normal, with the largest deviation from a normal distribution occurring in the right- and left-hand tails. However, a fairly large percentage of the respondents, nearly 22%, either refused to indicate the category in which their income lay or said that they did not know what their family income was. This implies that the size of the sample used for the actual test should be some 25-30% larger than calculated, to compensate for this large number of refusals. (Hopefully, not much bias will be introduced by this procedure). Figure 5.1 shows the distribution of total family incomes by categories for the sample pretested. Calculations on this distribution gave a mean of approximately 3.5 and a variance of approximately 1.8.

The distribution for monthly property tax payments for owned homes also seems to be approximately normal, with the largest deviation from normality appearing to be a small skewing toward the lower tax payments. Figure 5.2 shows the distribution of monthly property tax payments for owned homes by categories for the sample pretested. Calculations on this distribution gave a mean of approximately 3.9 and a variance of approximately 1.1. However, it should be noted

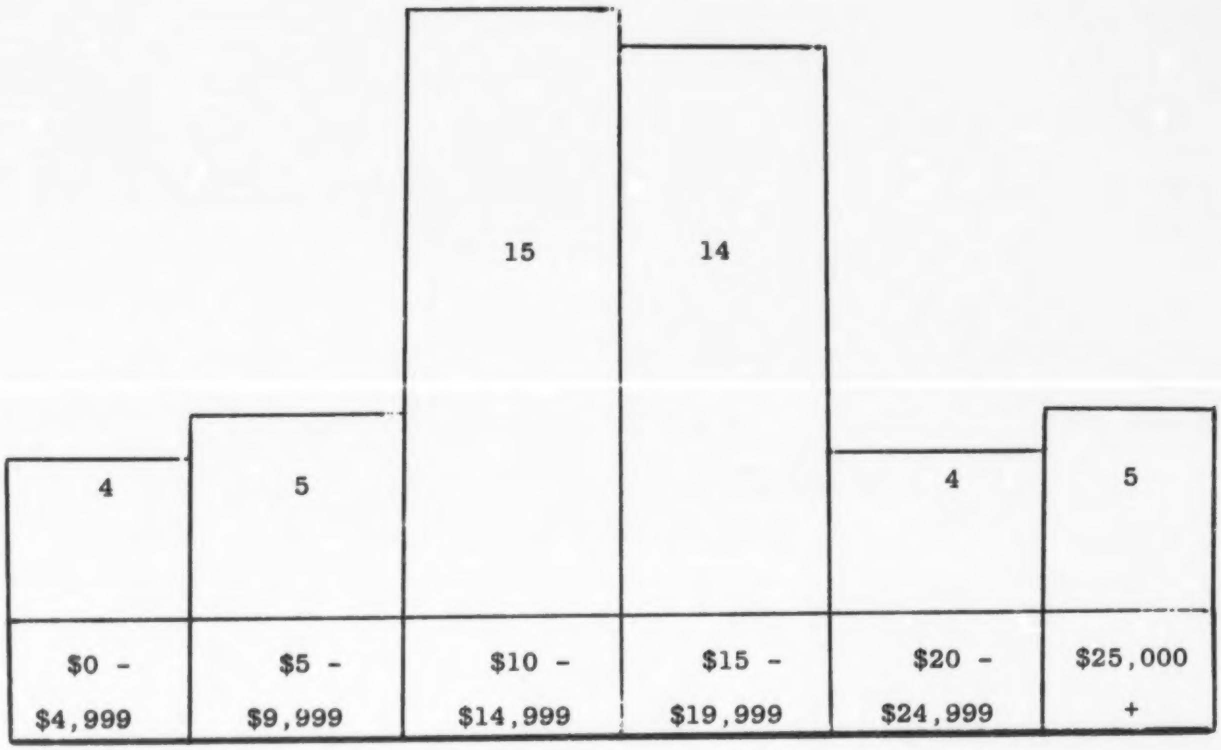

FIGURE 5.1

Distribution of Total Family Incomes for the Pretest Sample

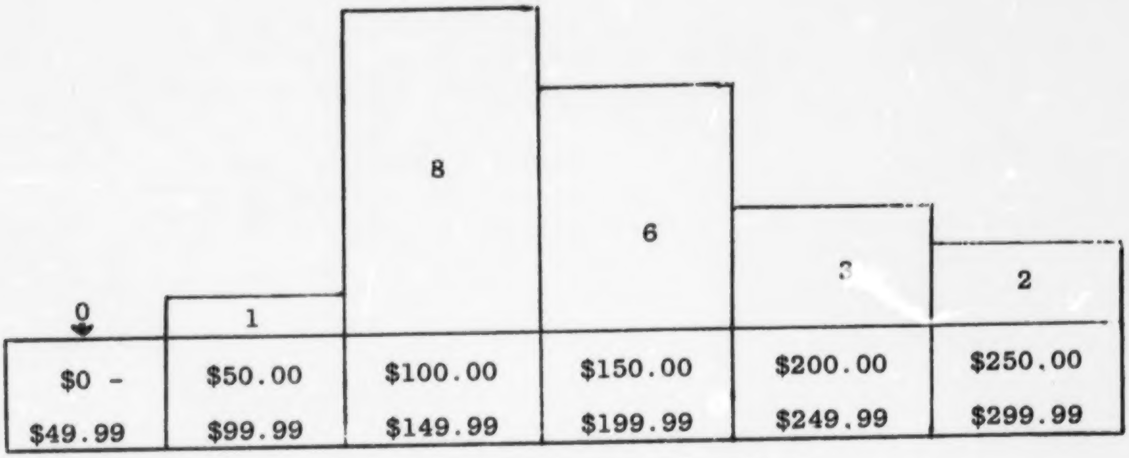

FIGURE 5.2

Distribution of Monthly Property Tax Payments
on Owned Homes for the Pretest Sample

that the sample on which these calculations are based is a little small, twenty; so that computations done on this sample certainly give rather gross approximations.

The distribution for rent is very unusual in that it is totally dissimilar from a normal distribution. The rent distribution appears to be a bimodal distribution with the two modes falling in the lowest and in the highest categories for rent. This distribution seems to be quite similar to one of the forms of the beta distribution. However, the distribution is based on a rather small sample, thirty-four; so that it is dangerous to draw conclusions on the basis of this distribution. (The peculiar form of the distribution for rents is probably due to the fact that for the pretest respondents were selected so that each belonged to a geographical cluster of respondents. This method of selection combined with the small number of clusters, six, has undoubtedly led to a non-random selection of housing types, due to the tendency of similar housing types to cluster together.) Figure 5.3 shows the distribution of rents by categories for the sample pretested. It can be concluded from this distribution that the actual survey should include a fairly large number of renters, so that any peculiarities in the distribution of rents due to the small size of the sample will be overwhelmed and eliminated.

Nearly 40% of the sample pretested had some sort of air conditioners, either partial or throughout the house. This implies that the total variation in annoyance with noise over the seasons will be substantially smaller than if air conditioners were not so popular. Those who have air conditioners will be far less annoyed by noise during the summer than those who don't. Around 53% of the sample have double-pane glass in their windows, or mentioned that they had storm

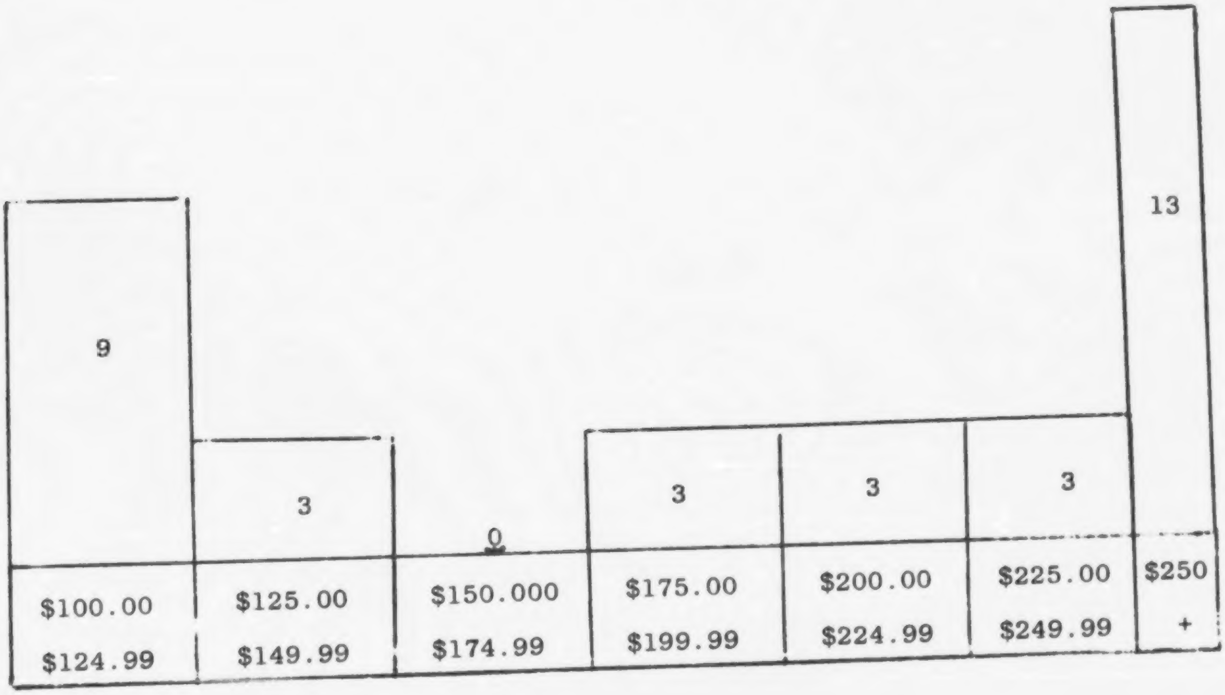

FIGURE 5.3

Distribution of Monthly Rent Payments for the Pretest Sample windows in response to this question. Storm windows could be most effective in reducing annoyance due to noise, since storm windows can be left up on the noisiest sides of the house during the summer. 70% of the sample had either air conditioning or double-pane windows (including storm windows) or both in their homes. This implies that a substantial part of the populace will be less willing to pay for noise reducing devices, since they have already spent money for such devices. The part of the population that has air conditioning and/or double-pane windows will not only be less annoyed by noise pollution than those who do not have such devices, but will be less willing to spend money for noise reduction, having already spent funds for this purpose.

Certain of the other results from the pretest also appear to be of interest, though they will not have any affect on the method of selecting the sample of persons to be interviewed for the actual test. It should be remembered, however, that these pretest results were derived from a rather small sample of respondents. Also, the distribution of rents seems to indicate a bias in the selection of renters away from those who pay moderate rents. Thus, one should be most careful in drawing any firm specific conclusions on the basis of the results presented below. Nevertheless, we believe that these pretest results do indicate certain general tendencies or trends in the data. We believe that certain very general conclusions may be drawn from the results presented, and that these results do indicate certain basic trends in the data.

First, the pretest results indicate that people in this area believe noise to be one of the most important environmental problems.

The people interviewed said that they considered noise to be the environmental problem that affects them most seriously, as compared to such other environmental problems as traffic and congestion, dirt and litter, air pollution, robbery and break-ins, and street crime and violence. (It should, of course, be remembered that the respondents chosen for the pretest were often selected to come from areas where there was believed to be traffic noise problems, such as areas near major highways.) The precise numerical ratings of environmental problems will be given below for the pretest sample. However, it seemed appropriate to divide the pretest respondents into renters and home owners, because it was believed that renters might be more critical with respect to environmental problems that home owners, since renters would seem to be less responsible and less blameable than would home owners. A statistical test on the difference between the renters' mean rating of noise and the home owners' mean rating of noise indicated that this difference was indeed significant.

The mean rating of the seriousness of noise by the renters compared to their mean ratings of the seriousness of other environmental problems is presented in Figure 5.4; while the home owners' mean rating of the seriousness of noise as compared to their mean ratings of other environmental problems is presented in Figure 5.5. The mean rating of the seriousness of noise for both renters and owners combined as compared to their mean ratings of other environmental problems is presented in Figure 5.6. The distributions of the noise ratings for renters, owners, and renters and owners combined are presented in Figures 5.7, 5.8, and 5.9 respectively. These distributions indicate something of a tendency of these seriousness of

Environmental Problems

	Mean	S.D.
Noise	6.0	3.2
Traffic and Congestion	5.4	3.3
Dirt and Litter	5.2	3.1
Air Pollution	5.1	3.5
Robbery and Break-ins	4.1	3.6
Street Crime and Violence	3.6	3.5

Figure 5.4

Mean Value of the Renters' Ratings of the Seriousness of Various Environmental Problems, from the Pretest

Environmental Problems

	Mean	S.D.
Noise	3.6	3.5
Traffic and Congestion	2.9	3.4
Dirt and Litter	3.4	3.8
Air Pollution	2.4	2.5
Robbery and Break-ins	2.1	3.1
Street Crime and Violence	0.5	1.1

Figure 5.5

Mean Values of the Home Owners' Ratings of the Seriousness of Various Environmental Problems, from the Pretest

Environmental Problems	Mean	S.D.
Noise	5.0	3.5
Traffic and Congestion	4.4	3.5
Dirt and Litter	4.4	3.5
Air Pollution	4.0	3.3
Robbery and Break-ins	3.3	3.5
Street Crime and Violence	2.3	3.2

Figure 5.6

Mean Values of the Combined Renters' and Home Owners' Ratings of the Seriousness of Various Environmental Problems, from the Pretest

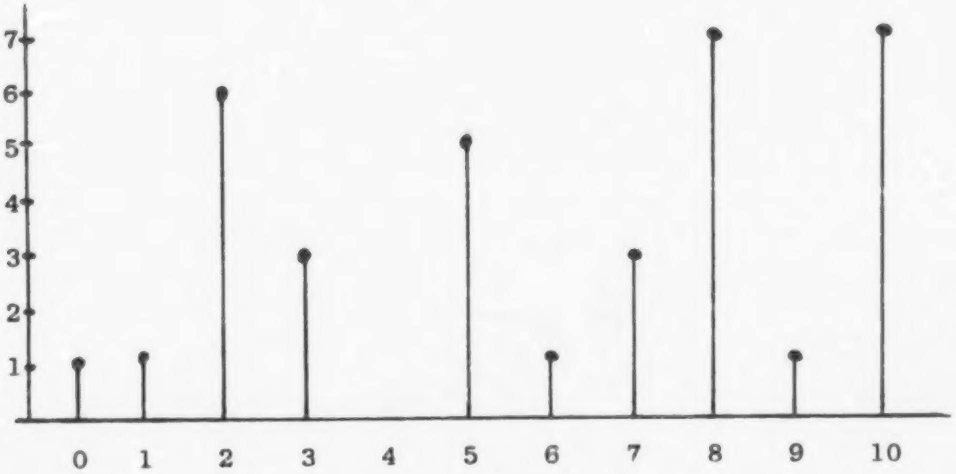

Figure 5.7

Distribution of Renters' Noise Ratings (in Comparison to Other Environmental Problems) from the Pretest

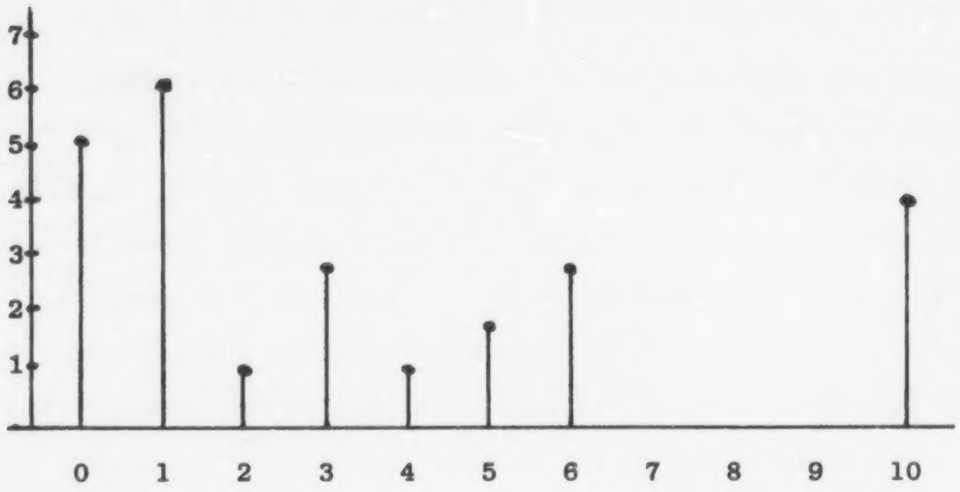

Figure 5.8

Distribution of Home Owners' Noise Ratings (in Comparison to Other Environmental Problems) from the Pretest

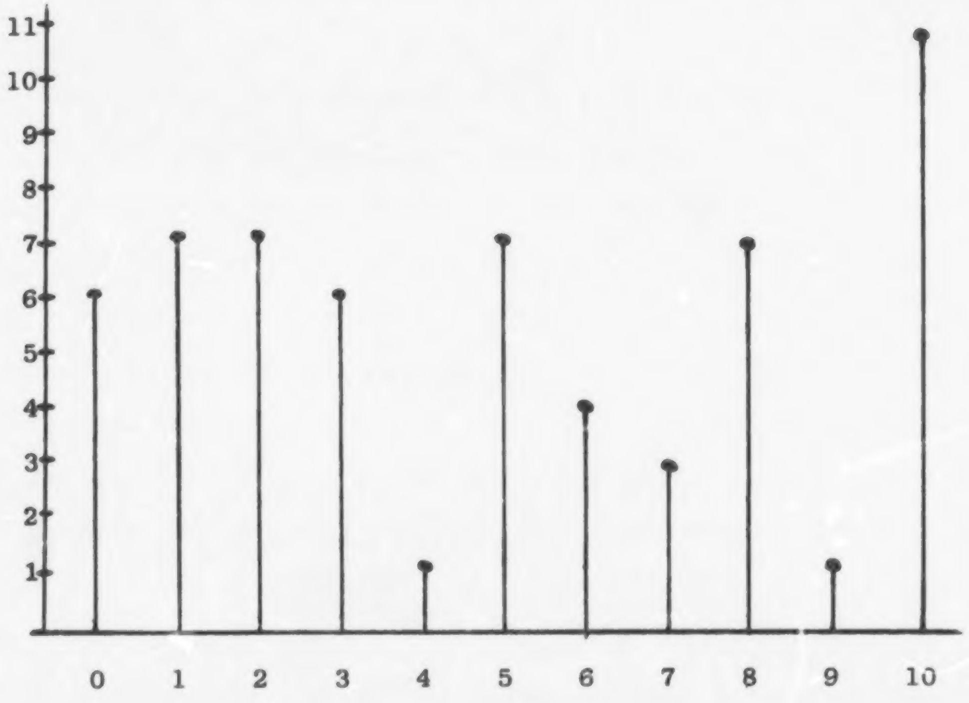

Figure 5.9

Distribution of Combined Renters' and Home Owners' Noise Ratings (in Comparison to Other Environmental Problems) from the Pretest noise ratings to cluster around the highest and the lowest ratings.

The ratings assigned by the respondents to the overall noise levels in their neighborhoods (from Question 40) are also rather interesting. Once more it seems appropriate to separate the respondents into renters and home owners, since renters may well be more critical of problems for which they are blameless. The mean rating on the seriousness of overall noise is 4.6 for renters and 2.5 for home owners. This does seem to indicate that home owners regard noise as a less serious problem than renters possibly because home owners usually live in more expensive, less densely populated and thus less noisy areas than renters and possibly because owners are better able financially and practically to take steps to reduce noise. The initial entries in Figures 5.4 and 5.5 are also the mean rankings assigned by the respondents to the annoyance caused them by the overall noise level. These mean rankings for disturbance caused by noise are 6.0 for renters and 3.6 for home owners. The differences between the renters' two mean rankings for annoyance caused by noise, 6.0 and 4.6, and between the home owners' two mean rankings for annoyance due to noise, 3.6 and 2.5, are sufficiently large to cause concern. It is disturbing that the responses to two different ways of asking the same basic question should be answers that vary so widely. Part of the explanation for these large differences in answers may be due to the smallness of the samples; part may also be due to flaws in the wording of the questions or to errors in administering the questionnaire. Nevertheless, it is certainly possible that these two different methods of asking the same basic question may produce different reactions in some respondents. The distributions of noise ratings for renters and home owners are presented in Figure 5.10 and Figure 5.11. These dis-

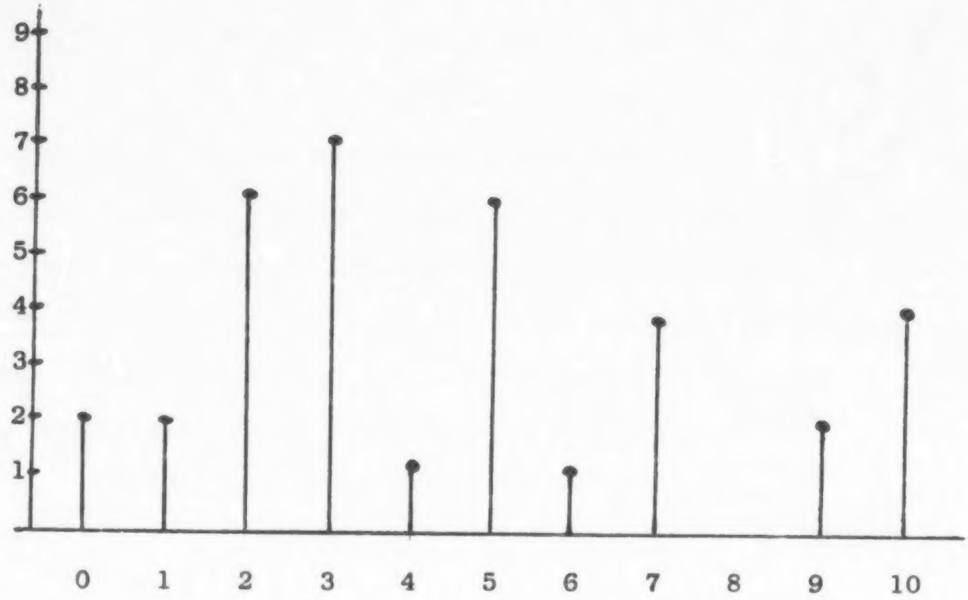

Figure 5.10

Distribution of Renters' Noise Ratings from the Pretest

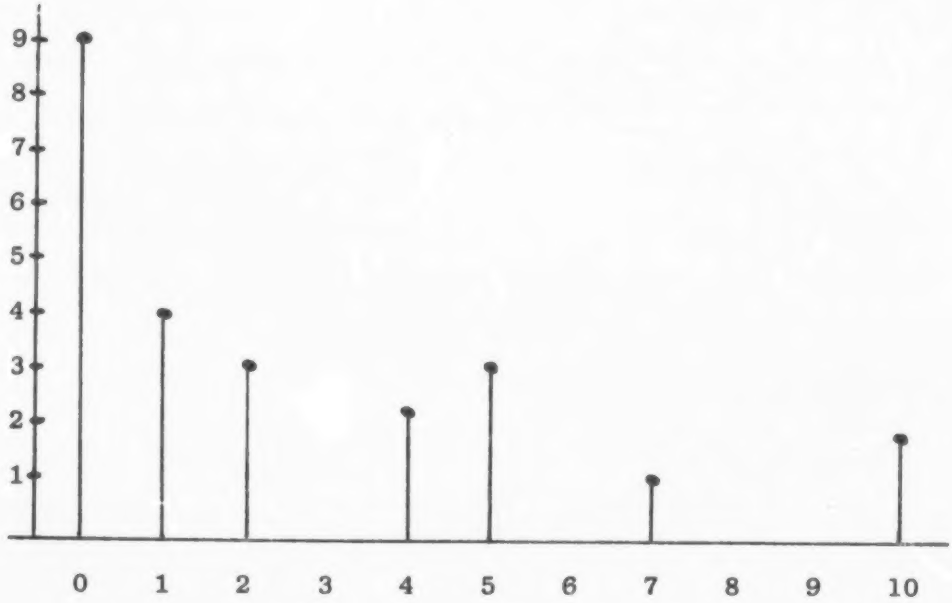

Figure 5.11

Distribution of Home Owners' Noise Ratings from the Pretest tributions differ very widely in their basic shape. Figures 5.10 and 5.11, of course, represent responses to basically the same question as Figures 5.7 and 5.8.

Another interesting difference between the reactions of renters and home owners to noise is shown by the relative importance assigned by each group to the various sources of noise. Figure 5.12 shows the mean rankings of five different noise sources by renters and home owners. These figures show that while renters consider large trucks to be the most important source of irritating noise, home owners consider regular automobile traffic to be the most annoying source of noise. The reason for this is probably the presence of more large trucks in the areas principally inhabited by renters, areas near large industrial and commercial establishments in many cases.

The pretest results giving personal willingness-to-pay for noise reduction are also rather interesting. Once more it seems desirable to separate the pretest sample into renters and home owners. One good reason for this separation is that home owners have somewhat higher incomes than renters. Since home owners have more money available to them than renters, home owners might well have either spent more or be willing to spend more for noise reduction than renters. Also, home owners usually live in less densely populated and thus less noisy areas than renters.

The pretest indicated that renters would be willing to spend on the average, about $2.00 per month ($24.00 per year) for unit reduction in annoyance due to noise (on the Noise Pollution Ladder) and on the average, more than $5.50 per month ($66.00 per year) for noise reduction to a point where noise was never at all annoying. On the other hand, the pretest indicated that home owners

Noise Sources	Means	
	Renters	Home Owners
Large Trucks and Buses	5.1	1.4
Small Trucks	3.5	1.3
Motorcycles	4.1	1.9
Sports Cars	2.3	1.5
Regular Automobiles	4.9	2.7

Figure 5 .12

Mean Rankings of Five Different Noise Sources by Renters and Home Owners would be willing to spend on the average, less than $.10 per month ($1.00 per year) for unit noise reduction and on the average, $2.50 per month ($30.00 per year) for noise reduction to a level that is never annoying. However, it should be pointed out that these figures, particularly those for home owners, are based on very small samples. Also, the standard deviations of the distributions for renters' and for home owners' willingness-to-pay for a noise reduction were rather high. That for renters for a noise reduction to a noise level that is never at all annoying was 8.6, while that for owners for the same noise reduction was 10.4. Such large standard deviations are due basically to the small size of the sample. Nevertheless, it is interesting that on the average renters are willing to pay more for noise reduction than home owners.

One explanation of this is that noise is less of a problem to home owners than it is to renters since home owners usually live in less densely populated and thus less noisy areas than renters. Also, it is suspected that home owners typically having more available income may well have already installed such noise reducing or noise averting devices as air conditioning or double-pane glass in their windows. Renters having less available income on the average would probably have installed fewer noise averting devices than home owners on the average. Unfortunately, the evidence from the pretest does not entirely support this hypothesis. More persons who have air conditioning or double-pane glass in their windows would pay nothing for any noise reduction than would pay something, which tends to support the hypothesis. But the responses of persons who do not have air conditioning or double-pane glass indicate that more of them would also pay nothing for noise reduction than would pay something, which tends to contradict the hypothesis. The basic reason for this contradictory evidence is probably the small size of the sample.

C. Selection of the Sample to be Interviewed in the Actual Test

The sample of people to be interviewed in the actual administration of the QEI Noise Pollution Questionnaire should be chosen to live in geographical clusters. Each respondent should be selected so that he lives close to fifteen or sixteen other respondents. The purpose of selecting the respondents from geographical clusters is to permit tests of differences in individual sensitivity to the same absolute level of noise. It has been well established that certain people are far more sensitive to noise than others, and one of the purposes of this questionnaire is to examine the variability in sensitivity to noise among individuals. A cluster size of 16 or 17 has been chosen on the basis of the assumption that there are precisely five levels of sensitivity to noise or five categories of annoyance with noise over which responses will be normally distributed. A standard statistical formula was used to calculate the number 16. (See Walpole, Ronald E., Introduction to Statistics, Macmillan, New York, 1968, p. 182.)

In addition, the sample of people to be interviewed will be chosen from areas that are not seriously affected by aircraft or airport noise. In this study we wished to avoid overlapping with other studies on the effects of aircraft and airport noise. Other than avoiding areas seriously affected by aircraft and airport noise, the selection of geographical clusters of people to interview should be performed at random over the entire Boston metropolitan area.

The minimum number of geographical clusters of sixteen persons each to be interviewed is determined in the following manner. The income distribution revealed by the pretest indicated that a minimum of around 62 persons would have to be interviewed to obtain a sample whose income distribution is identical to that of the entire Boston metropolitan area. Thus, any constraint imposed by income variability is obviously not binding, since far more than 62 people must be interviewed in the actual administration of this questionnaire. The principal constraint determining the size of the sample appears to be the difficulty in obtaining a good approximation to the distribution of rents. It seems appropriate to assume that all the members of each geographical cluster of respondents occupy similar housing. The housing in a geographical area will certainly not be precisely homogeneous, but should be similar enough that little harm will be done if it is assumed to be homogeneous. Thus, it is appropriate to consider the rent distribution of geographical clusters of homogeneous housing when attempting to determine the distribution of rents. Assuming the rent distribution to have seven categories over which clusters of homogeneous housing are normally distributed, the standard formula used before indicates that 35 geographical clusters are necessary to obtain a good approximation to the rent distribution. However, not all the housing in any cluster will be rented homes. Assuming that the pretest ratio of seven rented homes to five owned homes holds throughout the Boston area, it appears necessary to interview persons from around 60 geographical clusters ($35 \times (1 + \frac{5}{7})$). Thus, it appears necessary to interview about 960 people grouped in 60 geographical clusters of 16 people each.

Determining the seasonal period or duration of sampling is a rather difficult problem. However, since nearly 40% of the people of this region appear to have air conditioners, selecting the seasonal period is less critical than it at first appears to be. Only 60% of the population will be seriously affected by seasonal variations in the annoyance caused by noise pollution, since the remaining 40% having air conditioners will be largely shielded from these seasonal variations in noise. But, seasonal variations in annoyance from noise, due principally to the increased vulnerability of people to noise during the summer, is still a serious problem. There appear to be two possible solutions to this problem: (1) do all the interviewing during one particular period and then attempt to modify the results to take account of seasonal variations in noise level, and (2) test the respondents during the fall, winter, or spring and then retest them during the summer. Both of these methods involve problems, however. As to method #1, it is difficult to determine precisely how the results of a survey taken during one season should be modified to account for the seasonal variations in the effects of noise. The particular survey results and the direction of modification for taking account of seasonal variations in noise can indeed be determined, but the precise amounts of the modifications would be very difficult to estimate. As to method #2, it would appear to be fairly difficult to combine the information from a test with that from a retest at a different season on the same group of respondents. It would be quite difficult to estimate accurately the relative weights to be assigned to the results of the test and the retest. Information such as the presence or absence of an air conditioner in the respondent's home and his vacation plans would have to be included in the estimation of the size of the weights. Additional research thus must be done on this problem of the seasonal period of the sampling.

The distributional characteristics of the population to be sampled, principally the income variability of the population, must also be considered. However, as indicated before, the variation in income of the population could be estimated quite well using a sample of size 61 or 62, whereas we plan to sample about 960 persons, more than 15 times the number needed to indicate income variability. Other important distributional characteristics of the population might be age, commitment to the neighborhood and home ownership. Home ownership has been specifically included in the calculation of the sample size. Age and commitment to the neighborhood can both be reduced to variables having a small number of categories (for the purpose of considering effects of noise); so therefore, the variability in these factors too can be taken care of in our rather large sample.

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